PRINCIPLES OF PLANT PATHOLOGY

A Text and Laboratory Manual

PART I

OWENS

PAMPHLET COLL.

Principles of Plant Pathology

TEXT

IMPERIAL BUREAU OF MYCOLOGY

Part I

BY

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AT

Oregon Agricultural College

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PREFACE

The subject-matter presented in this manual has been selected to meet the needs of students in agriculture for a general course dealing with plant diseases and their control.

Plant pathologists have long been aware, and practical agriculturists should fully realize, that one of the important factors which interfere with maximum crop production as well as lower the quality of the product is the prevalence of plant diseases. When this fact is fully comprehended the conclusion necessarily follows that, in order to attain maximum production and to insure a product of high quality, diseases must be controlled.

In this volume the fundamental principles underlying the cause and control of plant disease will be emphasized. However, in order that these laws may be more thoroughly understood, some of the more important plant diseases of various types are outlined for study in such manner as to illustrate the applications of the principles involved.

Accordingly the treatment of the subject naturally falls into two parts as follows:

Part I.- The first part of the work consists of a discussion of topics of general interest concerning the nature, cause and control of plant diseases. The subject-matter of these general topics is indicated by the chapter headings, as, for example, historical account of the rise and development of the science of plant pathology, definition of plant disease, symptoms and signs of disease, classification of plant diseases, relation of plant diseases to environment, methods of investigating plant diseases by means of pure cultures and inoculations, methods of control such as the use of fungicides, quarantine and inspection, clean seed and nursery stock, immunization, storage and transportation problems, sick soil, relation of insects to plant diseases, and unsolved problems of plant pathology.

Part II.- In this part will be found a series of exercises covering representative types of plant diseases. The diseases outlined for laboratory study have been selected from as wide a field as possible, both as to causal agent and as to host, in order to give the student as broad a conception of the whole field of plant pathology as is possible for him to get in the limited time devoted to a course of this kind. Attention is called to the fact that under each disease listed the exercise falls into three subdivisions, namely, (1) directions for laboratory work, (2) a text discussion of the disease, and (3) a selected list of references to original literature on the subject.

For a number of years the writer has tried to present this course by sending the students to the library to look up the sources of information for themselves. This was found to be impractical with large classes of undergraduates because it required more of the student's time to get the desired material together than was available in his schedule for this course. Therefore, an attempt has been made to bring at least a part of the desired information together in this form. The

compilation has been accomplished in large part by making extensive quotations from original sources, such as bulletins and periodicals, and from books, wherever authentic and recent information could be found, on both the general subjects discussed in Part I and on the specific diseases outlined in Part II. Care has been exercised to give proper credit for all quoted matter, the quotation being inclosed in quotation marks and accompanied by the reference citation. It is felt that the compilation of essential facts under one cover as here presented will be a great time-saver for the student in thus making available for his study a selected list of the best articles on the subject without requiring so much of his time in looking up references in the library.

Acknowledgement is due H. P. Barss, Professor and Head of the Department of Botany and Plant Pathology at Oregon Agricultural College, whose interest in the work and whose helpful suggestions and criticisms have been of great value to the writer in compiling this manual. The writer has also consulted freely with Professor M. B. McKay and Dr. S. M. Zeller, Pathologists of the Oregon Experiment Station, upon subjects with which they are especially familiar.

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PART I.

CHAPTER I.

Historical: Rise and Development of Plant Pathology.

Plant diseases have been known since the dawn of history. Mention of blights, mildews, rusts and smuts occurs in the Bible and in the writings of the ancient Greeks and Romans. However, the ancients had no true, scientific knowledge of the causes of plant diseases and their observations and comments were largely of a superstitious nature. Throughout the ages down until the middle of the 19th. century the nature and cause of plant diseases was shrouded in mystery. All sorts of queer and groundless theories were advanced to explain the observed phenomena. The general tendency was to attribute the troubles to God or the gods, as the case might be, or to the influence of the heavenly bodies. Their nearest approach to truth was in attributing certain types of injury to environmental factors such as soil and climatic or weather conditions. In certain observations of this kind the ancients were fairly accurate.

The history of plant disease control parallels, in a general way, the growth of knowledge of the nature and cause of plant disease. As long as man was ignorant of the true nature and cause of plant diseases and tried to explain them on a supernatural or superstitious basis, just so long did he propose many remedies, based upon superstition, which had absolutely no value when viewed in the light of our present knowledge. But just as soon as he began to get a rational understanding of what causes disease, he was in a position to think out logical means of disease control.

In the earliest writings the references to plant diseases were very fragmentary and were scattered through the religious and historical writings of the Hebrews, Greeks and Romans. As time went on, the accounts of plant diseases came more and more to be segregated into writings on botany and agriculture. It was not, however, until the last half of the nineteenth century that a sufficient body of scientific knowledge on diseases of plants had accumulated to make it possible to organize a separate science of plant pathology. In the United States the first attempts toward organizing such a science occurred between 1870 and 1880. In 1873 instruction on plant diseases was first given in connection with botany by professor T. J. Burrill at the University of Illinois. In 1875 a special course in plant pathology as such was offered for the first time by Dr. W. G. Farlow at Harvard University.

Eras and Periods in the History of Plant Pathology.

It will be of interest and value to trace the growth of knowledge about plant diseases step by step in so far as this information has been recorded in written history. Whetzel (1)* has written a brief history of the development of the science of phytopathology. He has gone back into the earliest writings of the

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*Note.- These figures refer to literature cited at the end of the chapter.

ancients, hunted out the scattered references to plant diseases and traced the development of ideas as to their cause and control down through the ages to the present time. He divides his work into eras and periods, each of which stands for some definite step in the advancement of our knowledge of the subject. He names each period for some man who lived during the period and whose work stands out so pre-eminently that he can justly be said to have shaped the best thought of his time on the subject of plant diseases.

The following outline summarizes Whetzel's book in such a manner as to show, in chronological order, the trend of thought from the earliest times to the present:

I. The Ancient Era (From earliest times to end of 5th. Century A.D.)

A. Hebraic Period (To about 500 B.C.)

1. Includes centuries covered by the Old Testament to the rise of ancient Greece.

2. Data consist largely of mention of blightings, blastings, rusts, smuts and mildews.

3. The cause is laid to Deity.

B. Theophrastian Period (500 B.C. to 320 B.C.)

1. Cleidemus.- The first plant pathologist. His observations on the diseases of the fig, olive and vine were quoted by Aristotle.

2. Theophrastus (370 B.C. - 286 B.C.)

a. A pupil of Aristotle.

b. The first great botanist.

c. The following quotations from his work, "Historia Plantarum" show something of his knowledge of plants and his notions as to the cause of plant diseases:

"The fig is also often a victim to rot..... Scab chiefly occurs when there is not much rain, after the rising of the Pleiad."

"Moreover, there are certain affections, due to season or situation, which are likely to destroy the plant, but which one would not call diseases; I mean such affections as freezing and what some call scorching."

"As to diseases of seeds - some are common to all, as rust, some are peculiar to certain kinds.....

"Generally speaking, cereals are more liable to rust than pulses, and among these barley is more liable to it than wheat; while of barleys, some are more liable than others..... Moreover, the position and character of the land make

no small difference in this respect; for lands which are exposed to the wind and elevated are not liable to rust, or less so, while those that lie low and are not exposed to wind are more so. And rust occurs chiefly at full moon."

C. Plinian Period (320 B.C. to 476 A.D.)

1. Pliny.- A very voluminous writer on natural History. Lived 23 A.D. to 79 A.D.

2. Writings of Pliny and other Romans differ from those of the Greeks in some of the details, but there is general agreement in that both made certain accurate observations on susceptibility of certain plants to certain diseases and on the effect of weather conditions, while both held some very superstitious views as to the etiology of plant diseases in general.

3. An example of the odd mixture of accurate reasoning and blind superstition is found in Pliny's recommendations for the control of rust. He suggested sowing the grain early so that it will ripen before the rust comes on; and the sticking of laurel branches in the soil throughout the field so that the rust may go over on these. Columella, another Roman writer, suggested that frost injury in vineyards could be prevented by burning piles of chaff about the fields.

II. The Dark Era (476 A.D. to 1600 A.D.)

A. The period when science and learning slumbered.

B. Writings of this period show little that is new regarding plant diseases.

C. One bright spot in the darkness.

1. Ibn-al-Awam,- An Arabian country gentleman and agricultural encyclopedist.

a. Lived and wrote during 10th. century at Seville, Spain.

b. He was familiar with the writings of Pliny, Theophrastus and other ancient writers, but was also an independent observer and thinker.

c. He discussed diseases of trees and vines, describing symptoms of many diseases and giving consideration to their control.

D. The revival of interest in ancient Greek and Roman literature in the 14th. and 15th. centuries brought attention to Theophrastus and Pliny but the few writers on agriculture during the latter part of this dark era contented themselves with repeating merely the statements of the ancients.

III. The Pre-modern Era (1600 A.D. to about 1850 A.D.)

A. The Renaissance Period (17th. century).

1. The numerous records of plant diseases in the agricultural literature of the 17th. century are evidence of the revival of general interest in the subject.

2. There is evidence that this interest was strong among the educated gardeners and agriculturists.

3. Opinion as to the cause of disease was largely based on superstition and the philosophies of the ancients.

4. Attempts were made to develop practical methods of controlling plant diseases.

5. The first law directed toward plant disease control was enacted during this period. Rouen, France, in 1660, decreed the destruction of all barberry plants, since they were held to bear some mysterious relation to epiphytotics of wheat rust.

B. The Zallingerian Period.- Taxonomic Period (18th. Century).

1. Linnaeus' system of nomenclature was published in 1753. Naming and classifying was the order of the day.

2. Names of plant diseases and classifications were largely copied and adapted after supposedly similar diseases in man and animals.

3. The trend of thought was influenced by (a) taxonomic philosophers and medical men, and (b) practical gardeners. Consequently there were two points of view, namely, (1) the philosophic and (2) the practical.

4. Prominent workers of the period.

a. Tournefort (Frenchman)
Classification of plant diseases (1705)
(1) Due to external causes.
(2) Due to internal causes.

b. Eysfarth (German).
Classification of plant diseases (1723).
(1) Diseases of germinating period.
(2) Diseases of vegetative period.
(3) Diseases of fruiting period.

c. Fabricius (Dane)
This man was seventy-five years ahead of his day, holding (1774) that fungi found associated with disease lesions are distinct organisms, and not morbid plant tissue. His

contemporaries were not ready for this advanced idea, however, and his writings had little influence upon the phytopathologic thought of his time.

d. Zallinger.
Classification (1773)
(1) Phlegmasiae: inflammatory diseases.
(2) Paralysis: debility.
(3) Discharges or draining.
(4) Cachexia: bad constitution.
(5) Chief defects of different organs.
Zallinger put forth and emphasized the causal nature of environmental factors such as, drought, drying winds, hail, freezing, unfavorable soil.

5. Summary of Zallingerian Period.

a. The phytopathologic thought and writings were distinctly taxonomic.

b. The basis of classification was largely symptomologic.

c. Modern practices in plant disease control were beginning to take form.

d. In attempting to explain the cause of plant diseases most of the workers of this period still resorted to the ancient philosophies, to superstition or to the effects of the elements, such as winds, low temperature and unfavorable soil.

e. In spite of this general clinging to the old ideas by the majority, yet, in the minds of some, a new idea was gradually crystallizing. This was the idea that plant diseases arise through the deranged physiology of the plant. This idea became the dominant one of the next period.

C. The Ungerian period (1807-1853).

1. This is known as the physiologic or Autogenetic period.

2. Leaders.

a. Unger: Believed that disease is brought about by the internal disorganization of the nutrition processes.

b. Meyen: A brilliant botanist but followed Zallinger's philosophy.

3. Summary:

a. The thought of this period on plant diseases was distinctly physiologic, with a tendency toward the mycologic near the end of the period.

b. Plant diseases were classified on the basis of cause in spite of the fact that pathologists would not admit the causal relation of the fungi they had been finding associated with diseases.

c. The influence of the practical gardener on the phytopathological writings of the period were overshadowed by the researches and activities of the scientists.

d. The influence of human medicine was still strongly felt.

e. The cause of disease in plants was held to be autogenetic.

f. Transition Period. It was being observed more and more that fungi were very generally associated with disease lesions. This kept raising the question as to whether the fungi might not be the cause rather than the result of the disease.

IV. The Modern Era (1853-1906).

A. The Kuhnian period (1853-1883).

1. This period is characterized by the almost universal study of the causal relation of fungi to plant diseases. The pathogenetic period.

2. Leaders.

a. Anton de Bary: worked out the life histories of fungi and established their relationship to diseases. One of this classical pieces of work was the establishment of the relation of the cup stage on barberry to the wheat rust fungus.

b. Kuhn: Wrote the first text-book of plant pathology based upon the true nature of the cause of plant diseases due to parasites.

c. Berkeley: An English mycologist who was interested in the practical side of his science and addressed his writings largely to the practical growers.

3. Summary:

a. The thought and works of the time were decidedly mycologic.

b. The basis of classification was entirely etiologic; that is diseases were classified as to cause.

c. The influence of the gardener, forester and farmer was decidedly marked.

d. The autogenetic theory of plant disease was no longer tenable after the convincing demonstrations of the pathogenic nature of fungi.

e. The control of plant diseases was placed upon a sound basis by the establishment of the causal relations.

B. The Millardetian Period (1883-1906).

1. Leading European plant pathologists:

a. Millardet: Discovered Bordeaux mixture.
b. Wakker: worked out a bacterial disease of hyacinths.
c. Hartig: A forest pathologist.
d. Brefeld: Published smut investigations and others.
e. Jensen: Hot water treatment for grain smuts.
f. Eriksson: Grain rust investigations.
g. McAlpine: The diseases of cereals and fruits in Australia.
h. Prillieux: Founder of Phytopathology in France.
i. Ward in England: Postrup and Rawn in Denmark: Woronin in Russia; Frank, Klebahn and Sorauer in Germany are other workers who have contributed to plant pathological knowledge.

2. Leaders in the development of plant pathology in America.

a. F. L. Scribner: First Federal Pathologist.
b. B. T. Galloway: First Chief of Bureau of Plant Industry.
c. E. F. Smith: Father of bacterio-phytopathology.
d. J. C. Arthur: Rust specialist.
e. T. J. Burrill: Discovered bacterial cause of Fire-blight.
f. G. F. Atkinson: Botanist and plant pathologist.
g. L. R. Jones: Investigator and teacher of plant pathology.

3. The establishment of a Section of Mycology of the Botanical Division of the U. S. Department of Agriculture, July 1, 1886, was a land mark in the rise and development of Plant Pathology in America.

V. The Present Era (1906--).

A. The establishment of chairs of plant pathology in universities and colleges of agriculture.

1. At Cornell University in 1907.

2. At University of Wisconsin in 1909.

3. At Minnesota. Division of the Botany Department.

4. At Illinois. " " " " "

5. At Iowa State College, Div. " "

B. Establishment of the American Phytopathological Society, 1909.

C. United States Quarantine Act of 1912.

D. Introduction of sulfur as a substitute for copper in fungicides.

1. Sulfur had long been used as insecticide and dormant fungicide.

2. Cordley used dilute solutions of lime-sulfur as summer spray, 1906.

3. Scott used self-boiled lime-sulfur on peach foliage.

4. Growing use of sulfur in dust form.

E. Development of disease-resistant crops.

Additional land-marks in plant disease history.

The following chronological list of events was compiled by Stevens (2) and includes some steps in the development of the science which were not mentioned in the work of Whetzel outlined above.

"1683 The discovery of bacteria. Loewenhoek.
1807 The efficiency of copper against smut spores discussed. Prevost.
1821 The use of sulfur as a fungicide recommended. Robertson.
1845 The use of boiled sulfur and lime for mildew advocated.
1861 The publication of the first American paper on plant pathology. Englemann.
1860-1864 The founding of bacteriology. Pasteur.
1864 The proof of alternation of hosts, heteroecism. De Bary.
1869 The first university publication in America regarding plant pathology. University of Illinois.
1873 Plant pathology taught incidentally with botany in America. Burrill.
1875 Plant pathology first taught as a special subject in America. Farlow.
1880 The discovery of the cyclone principle in nozzles. Barnard.
1884 Systematic introduction of plant pathology into American Agricultural Experiment Station work. Arthur.
1885 The announcement of the Bordeaux mixture. Millardet.
1886 Proof that mosaic is infectious. Mayer.
1888 The introduction of formalin as a disinfectant. Trillat.
1888 Organization of the State Agricultural Experiment Stations.
1890 The beginning of pump improvement for spraying.
1894 Establishment of the fact that biologic races exist.
1906 The passage by Congress of the Adams Act."

History of plant pathology closely related to history of botany.

Duggar (3) gives an historical discussion of various phases of botanical science and shows how advances in these branches have contributed largely to the development of the science of plant pathology. The following quotations from his book are interesting and instructive in this connection.

"A proper study of the fungous diseases of plants is at once scientific and practical. The fungi were carefully studied, however, long before their importance as disease-producing organisms was recognized. A history of our knowledge of the fungi in general, therefore, takes us through periods when the scientific and the practical attitudes were not associated; yet a brief historical survey must develop important and interesting facts bearing upon the relations of scientific work to practical affairs.

"Systematic mycology. A careful study of the fungi as independent groups of plants was begun in the latter part of the eighteenth century, and if we examine the results of the work beginning at that time and continuing into the early half of the nineteenth century, it will be found that this period was one of most accurate and painstaking endeavor in systematic mycology. Much credit is therefore due to the more prominent students of that time, such as Bulliard, Persoon, Nees von Esenbeck, Schweinitz, Leveille, Fries, and Berkeley. The work so well begun was continued into the second half of the same century, and among the names particularly associated with that period are those of Fuckel, Karsten, the Tulasne brothers, Corda and many others. This systematic study has, of course, continued to the present time, although the nature of the work produced has undergone important changes.....

"Physiology and morphology.- The progress in systematic mycology has made possible for more than half a century a comprehensive study of the diseases of plants; yet systematic study alone is not responsible for the rapid progress subsequently achieved in plant pathology. A number of causes might be suggested as of importance in the development of the latter field. It should not be overlooked that advances in general plant physiology were also manifest at about the beginning of the nineteenth century, and that this phase of botany had undergone unusual development toward the middle of the century, under the influence of Sachs and other experimentalists of his time. Again, a more intensive method in the study of morphology had been introduced, and in mycology the efforts of such men as the Tulasne brothers had shown what could be done in carefully following out the life histories or development of the fungi. Beginning about the middle of the nineteenth century, another distinctive epoch is entered upon, and the developments of this period are due chiefly to Anton De Bary and his contemporaries.

"The rise of plant pathology.- De Bary became the conspicuous leader in this field, establishing in an incontrovertible manner the connection between the polymorphic stages of certain parasitic species, and the possibility of following, under well-controlled conditions, the development of little-known groups. His work was, furthermore, particularly significant in that he so thoroughly appreciated the nature of parasitism, the epidemic character of fungous diseases of plants and the practical value of methods of inoculation and infection. To him more than to any one else we owe the influence which directed future work along the lines of

the most profitable research. This period witnessed also the advances made by Pasteur and others in the study of fermentation and disease, and it was closely followed by those perfections in the development of pure culture methods which have finally resulted in the possibility of cultivating practically all bacteria and a very great majority of the fungi. In the study of the fungi as the cause of plant diseases, at this time, valuable service was also done by Kuhn, who in his early career devoted himself particularly to a study of the fungous parasites of cultivated plants. The last decades of the century yield work of such diversity and importance that it is impossible here to do more than make briefest reference to it. The work of Brefeld is perhaps most distinctive, and while his theoretical views have not had a host of followers, his fundamental studies in the general field of mycology, and particularly, in this connection, his wide range of experiments in the artificial cultivation of organisms, are invaluable. Among many others who contributed special service in some phase of pathological or general mycological work of that time may be mentioned also Frank, Hartig, Schroeter, Sorauer, and Winter in Germany; Oudemans in Holland; Cornu, Millardet, and Prillieux in France; Comes in Italy; Woronin in Russia; Eriksson in Scandinavia; Plowright and Ward in England; Farlow, Burrill, and many others in the United States. The work has continued vigorously, investigations and problems have multiplied, and with adequate conservatism the outlook is most encouraging."- Duggar, B. M. Fungous Diseases of Plants. pp. 1-3. 1909.

Growth of plant pathology in the United States.

Further historical facts, especially dealing with the establishment and growth of work in plant pathology in the United States are set forth in the following passages from Stevens (2):

"A series of papers begun by Burrill in 1873, another by Farlow in 1875, and other publications by Bessey, contributed to the knowledge of plant diseases and served especially to awaken interest in the problems of, and to attract students to this field of research.

"In 1879 Burrill, working upon the blight of the pear and apple, was the first to attribute a plant disease to bacterial origin. His work was confirmed and his conclusions more fully established by Arthur.

"During the seventies, from two or three workers in this field, the number rapidly grew, augmented in the middle eighties by the introduction of plant pathology into the Agricultural Experiment Stations and the United States Department of Agriculture, until the number of papers published in the United States upon plant pathology between 1888 and 1900 is estimated at over four thousand. While only a few dozen plant diseases had been even cursorily described in the United States prior to 1880, in 1910 a total of some 525 diseases, of which more than 250 were serious, had been carefully investigated and the number since that date has been greatly increased."- Stevens, F. L. Diseases of Economic plants (Revised Edition). pp. 1-3. 1921.

History of plant disease control.

As one would naturally expect, the early attempts at plant disease control were just as fantastic and just as irrational as were the theories as to the cause of disease. Stevens (2) has compiled some interesting examples of these early recipes and formulas. It is interesting to pick out the ones which are really effective and to note whether they were based on life history facts known at the time or were purely empirical and just happened to hit rather than miss. The following is quoted verbatim from Stevens:

"Though little could be done to devise rational methods of combating plant diseases until their causes were known, a very few rule-of-thumb, empirical ways of meeting them had been suggested in very early days. As might be expected, many of the methods used were valueless. Thus Parkinson early in the seventeenth century advocated the use of vinegar to prevent canker on trees, and Forsyth in 1790 gave the following directions for making a mixture to 'cure disease, defects, and injuries of plants'. 'Take one bushel fresh cow dung, one half bushel lime rubbish from old buildings, one half bushel wood ashes, one sixteenth bushel pit or river sand. The last three are to be sifted fine before they are mixed. Then work them well together with a spade, and afterward with a wooden beater until the stuff is very smooth, like fine plaster used for the ceilings of rooms.' Soapsuds or urine was used to make the composition of the consistency of plaster or paint. After being applied it was covered with a sifting of powder made of 'dry powder of wood ashes, mixed with the sixth part of the same quantity of the ashes of burnt bones.'

"Among the early chaff, however, there were some grains of wheat. Thus Riedel in 1751 advised excision followed by grafting wax for canker, and Robertson in 1821 said: 'Sulfur is the only specific remedy that can be named for the treatment of mildew on peaches. It should be mixed with soapsuds and then applied by dashing it violently against the trees by means of a rose syringe;' thus advocating a remedy which, modified, is still prominent for this class of diseases.

"The aggressiveness of several plant diseases in Europe between 1876 and 1882, particularly the downy-mildew upon the grape, which, about 1878, had invaded Europe from America, stimulated a search in the former country for effective spraying mixtures. Trials of many chemicals were made, but it was left to accident to suggest, and to the genius of Millardet, of Bordeaux, France, to perfect, the happy combination of lime and bluestone that we now know as Bordeaux mixture. It was customary in certain vineyards to sprinkle a few rows of grape vines near the road with a mixture of milk of lime and bluestone to give them a poisonous appearance to ward off depredation of the hungry passer-by. The vines so treated in 1882 were noted by Prillieux and Millardet to be less injured by the mildew than were other vines, and they ascribed the beneficial effect to its proper cause, the lime-bluestone mixture.

"While several investigators were engaged simultaneously in experimenting with these chemicals upon the mildew, it was Millardet who first planned and executed experiments and published results which demonstrated the commercial value of the lime-bluestone treatment.

"The first systematic applications of copper, and of copper with lime as a disease preventive, were made under the direction of Millardet, August 18, 1883. In 1884 the work was repeated, and in 1885 Millardet published the first directions for preparing Bordeaux mixture:

Water - - - - - - - - - - - - - -	130 liters	(34 gallons)
Bluestone - - - - - - - - - - - -	8 kilograms	(17.6 pounds)
Lime - - - - - - - - - - - - - - -	15 kilograms	(33 pounds)

"This mixture was to be shaken upon the plants with a broom.

"Following this demonstration came the introduction of an era, not yet at an end, of active experimentation with fungicides, wet and dry, which has already yielded results of incalculable value.

"In 1885 also appeared for the first time the Ammoniacal Copper Carbonate proposed by Professor Audoynaud of the Montpelier Agricultural School.

"Saunders, in the Canadian Horticulturist in 1884, suggested the use of several liquid spraying mixtures for apple scab, but little if any liquid spraying for plant diseases was done in America prior to 1885.

"In 1885, from the Section of Mycology, Division of Botany, United States Department of Agriculture, appeared an article by Lamson-Scribner, giving directions for making 'the copper mixture of Gironde', the primitive Bordeaux mixture. In 1886 the spraying compaign may be said to have been well started in this country.

"The disinfection of seeds by bluestone was practiced first with the cereals as early as 1807 by Prevost of France, and improved by Dreisch in 1873, by the addition of a limewater bath to follow the bluestone. In 1887 Jensen of Denmark improved upon these methods by developing his hotwater treatment, which has since proved of great value, not so much for its primary use, in which it has been superseded by formalin, but owing to its applicability to those loose smuts which cannot be successfully treated by surface disinfection. Similar seed treatments have been extended to the potato by Bolley and to cabbage by Harding.

"The production, by breeding, of new and disease-resistant varieties is one of the latest and most promising methods of combating plant diseases. Grapes resistant to Phylloxera were produced by Millardet; cotton, cowpeas, and watermelons resistant to wilt by Orton; cabbage by Jones; tomato by Durst and others; tobacco resistant to Thielavia by Johnson.

"No small part in the progress that has been made in the prevention of plant disease is due to the improvement of applicances, dusters, pumps, nozzles, etc., for distributing the disinfectants upon the plants. This progress is well illustrated by comparing the broom of Millardet with the knapsack, barrel, or power sprayer of to-day.- Stevens, F. L. Diseases of Economic Plants (Revised Edition) pp. 3-7. 1921.

General Summary.

It is clearly evident that the history of phytopathology is part and parcel of the history of botany. In early times the notions as to the nature of plant diseases were as hazy as the ideas about the nature of plants and living things in general. There was a gradual evolution of thought on this subject from the ancient habit of trying to explain everything as subject to the whims of the gods, or the influence of the planets, through the autogenetic theory of the cause of diseases, and finally arriving at the true, or pathogenetic theory which really explains parasitic diseases in their true light.

References.

(1) Whetzel, H. H. History of Phytopathology. 1918.

(2) Stevens, F. L. Diseases of Economic Plants (Revised Edition). 1921.

(3) Duggar, B. M. Fungous Diseases of Plants. 1909.

CHAPTER II.

Modern Plant Pathology.

In the preceding chapter it was pointed out that the development of the science of plant pathology was very closely related to, and parallel with the rise and growth of botanical knowledge. The modern plant pathologist is cognizant of his constant dependence upon the botanical sciences in his investigations of plant diseases. Some of the phases of botany, a knowledge of which is more or less indispensable to the phytopathologist are Mycology, Morphology, Anatomy and Histology. Physiology, Cytology, Plant Genetics, Ecology and Bacteriology.

The botanical sciences are not, however, the only ones concerned in a study of plant diseases. Chemistry and physics, especially the former, are of importance. A knowledge of certain phases of Chemistry is especially necessary in such studies as the physiology of fungi. In fact, there are very many points of contact between chemistry and plant pathology.

A somewhat more detailed discussion of the dependence of plant pathology upon various phases of botany should be of value at this point. Duggar (1) has discussed certain of these aspects of modern plant pathology and the following quotations give his point of view:

Mycological relations.

"The mycological aspect will be concerned more particularly with a minute investigation of the fungi from systematic, morphological, and physiological standpoints. Too often, in the early work, the chief object of the study has been to identify the fungus associated with a given disease and to describe its fruiting stages. An investigation of the fungus, however, should include an account of its complete life history wherever possible, the relations of the fungus to conditions under which it is injurious, the conditions under which fruiting stages may be developed, etc. In the course of time, therefore, it will be necessary to repeat much of the work of earlier date, which has seemed to be more or less complete.

Anatomical effects.

"The anatomical study, in the sense in which it is here used, will be concerned with the relations of the host to the parasite, in so far as the former may be modified in growth or minute structure. All lesions, hypetrophies, or other structural changes produced in the host plant are worthy of the closest attention. These changes in the host are most diverse, varying, on the one hand from minute modifications of a single cell, or of a small group of cells, to those changes of form which involve an immense increase in the size of the host organism, often giving rise to relatively enormous deformities. Such as may be noted in the case of the club root of cabbage, plum pockets, cankers, and smut of corn. Again, the

deformities may result in the pushing into growth of an abnormal number of buds, in many instances accompanied by decreased size of the branches and changes in the trophic relations, such as to develop the various forms of witches' brooms. The anatomical changes in the host are those most commonly termed pathological changes. Unfortunately these are often discussed as the chief evident pathological effects in many cases, and for that reason they constitute in the popular view that which is properly designated 'plant pathology'.

Physiological relations.

"In close connection with the anatomical changes produced in the host, a study should be made of the physiological relations of host and parasite, particularly of the physiological disturbances in the host itself. The normal physiology of the host requires attention in order that a proper comparative study may be made. The conditions which predispose the host plant to attack, or, in other words, the conditions favorable to the penetration of the fungus and its development within the host are most fundamental from the standpoint of pathology, and also in order that control measures may be properly developed. It is a direction in which future work promises most profitable returns. Very little of lasting value has been done towards determining the exact conditions under which the host plant is most susceptible to attack. It is well known in the case of certain forced plants that the undue suffusion of the plant with water, whether due to lack of ventilation or to a combination of causes, is a certain factor in inducing disease. Under such conditions many fungi are able to gain entrance and become the cause of epidemics, whereas, under more normal conditions, they may remain as harmless inhabitants of dead materials.

"Every season shows differences in the prevalence of the more injurious fungous diseases. One season the brown rot of the peach may affect only extremely sensitive varieties, and the following season it may cause the loss of those most resistant. Again, some varieties of the host may be, under most conditions, but slightly predisposed to attack, notable instances being those of the very slight predisposition of the Kieffer pear to the blight, or in the resistance of certain American varieties of grapes to the downy mildew. Such cases might be multiplied indefinitely, and, in fact, there is scarcely a known fungous disease of the variable cultivated crops with reference to which all varieties of the host plant are equally susceptible. This important fact has led to the selection and to the production through hybridization of varieties which shall at once possess both the qualities desired from the standpoint of their own fruits or other products, and which shall, at the same time, carry with them the high resistance necessary to enable t em to compete with the fungous pests.

"The effect of the fungus upon the host may be, further, merely to modify the quality of the product, such as the sugar or starch content, without seriously affecting the appearance of the economic product. In fact, the different means whereby the effect of the fungus may show itself in slight physiological disturbances of the host are too numerous for special consideration." - Duggar, B. M., Fungous Diseases of Plants, pp. 5-7. 1909.

Cytology and plant genetics.

Cytology or the study of the cell plays a part in many investigations in plant pathology. The organism causing the club-root of cabbage lives in close association with the host protoplasm in the cells of the diseased roots. A correct understanding of the relation of parasite to host necessitates a careful cytological study of the affected tissues.

The laws of heredity are based upon certain cytological facts and the breeding of plants immune to disease must necessarily depend upon a knowledge of these cell phenomena and the laws governing the inheritance of the characters of resistance and susceptibility. The subject of immunization will be discussed more at length in chapter XI. These examples serve to show that the plant pathologist has frequent need for a knowledge of cytology and plant genetics.

Ecological relations.

Ecology treats of the relation of plants to their environment. Plant diseases, both parasitic and non-parasitic are very intimately affected by environmental factors such as soil and climatic or weather conditions. These factors affect the host directly in the case of the non-parasitic diseases, and in the case of parasitic diseases they exert a profound influence upon the activities of the causal organism in addition to whatever direct effect they may have upon the host. For a further discussion of the relation of plant diseases to their environment see chapter V.

Bacteriology.

Many plant diseases are caused by bacteria and consequently a knowledge of these organisms is necessary in order to combat this type of disease. Bacteriology is a recent off-spring from botany, but bacteriologists have developed an extensive science and technique which is very useful to the plant pathologist.

Zoology.

By far the greater part of the injuries to plants caused by animal life comes from the insects and is properly handled by the entomologists. However, there is one group of animals which causes enormous damage to plants, but which, by common consent, is turned over to the plant pathologists rather than to the entomologists or zoologists for investigation. This group consists of the eel-worms or nematodes. These minute worms cause a variety of injuries to plants.

Their depredations are so widespread and the problems connected with the investigation of this group of plant pests are so extensive, that there has arisen a distinct branch of plant pathology known as nematology, the exclusive field of which is the investigation of plant diseases caused by eelworms.

References.

(1) Duggar, B. M. Fungous Diseases of Plants. 1909.

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CHAPTER III.

Definition, Symptoms and Classification of Plant Diseases.

In order that the student may have a more definite conception of the fundamental items of the subject-matter of this course, it is desirable that he should formulate a rather clear definition of disease in plants, that he should know how to recognize the symptoms which indicate an unhealthy condition and that he should have a satisfactory basis on which to classify the various maladies which he will study.

A. Definition of Plant Disease and Plant Pathology.

That it is difficult to formulate a good definition of disease in plants is evidenced by the variety of opinions expressed in the following definitions compiled from a number of sources. Read them carefully and decide which one is most acceptable.

"I do not regard the investigation of the phenomena of mere sickliness as the task of pathology. It is only when the sickly condition leads to the death of some part of the plant that we may speak of actual disease."-- Hartig, Robert. Diseases of Trees. p. 5. 1894.

"By disease in plants is meant an abnormal condition, injurious to a part or all of the plant, due to the continued interposition of some chief causal factor, exhibited through abnormal cellular activity, and expressed in abnormalities of various kinds." - Whetzel, H. H. In mimeographed lecture outlines for plant pathology at Cornell University.

"Disease, therefore, may be said to be variation of functions in directions, or to extents, which threaten the life of the plant, the normal in all cases being the state of the plant characteristic of the species." - Ward, H. Marshall. Disease in plants. p. 93. 1901.

"If we accept a rather broad definition that disease in plants includes the effect of every unfavorable factor entering into the life of the plant it follows that various agencies of the living and non-living environment may be responsible for the condition known as disease." - Morse, W. J. and C. E. Lewis Maine Apple Diseases. Maine Exp. Sta. Bull. 185: 339. Dec., 1910.

"If we call 'sick' only those cases in which the organism undergoes such a disturbance in its functions that its existence seems threatened, we will be in a dilemma when we consider the changing developmental forms of our cultivated plants, for we will then discover that the above explanation is insufficient.....

"....In treating questions of disease, we shall have to follow two lines of work. We must naturally first keep the organism's aim in sight. And this aim, which the organism derives from its very origin, is to live, and in fact to live

as long as possible. ....In following the second line, the aim of cultivation, developed from the relation of the plants to human needs, is an added important factor. These conditions of the vegetable organism opposing our cultural endeavors will be combated as inexpedient. But such conditions need in no way threaten the existence of the individual and therefore, according to the above explanation, are not diseases. Yet they belong to the province of the pathologist as disturbances which must be considered and overcome.....

"The consideration of the cultural needs forces us to the following division of our subject: first of all, we will have to consider all cases which threaten the individual aim of the organism, i.e. its longest possible life; - these are absolute diseases. Then we must discuss the disturbances which the momentary cultural aim experiences and which we term relative diseases. These relative diseases may vary since what cultivation considers worth striving for today may be neglected tomorrow." - Sorauer, Paul. Manual of Plant Diseases, Vol. 1. pp. 5-7. (English translation by Frances Dorrance).

"A disease, in the ordinary acceptation of the term, is an abnormal condition of the organ, interfering with the use for which it was intended, or threatening its life, in whole or in part. It is a derangement of function, associated with corresponding changes in structure....." - McAlpine, D. Bitter Pit Investigation. First Progress Report, 1911-12.

"If we interpret disease as any apparently abnormal condition of an organism or of its parts or functions, it is evident that the diseases of plants, like those of other living things, include morphological and physiological disturbances which may be induced by a variety of environmental factors, living or non-living. The popular conception excludes from the category of plant diseases those effects caused by predatory animals or by sudden mechanical means. There is also a tendency to dissociate from plant diseases proper the wide-spread devastation which is the result of the varied injuries annually inflicted by insects. In general, therefore, we may disregard insects as the cause of plant diseases when that term is applied narrowly.

"It is within comparatively recent times that the specific injuries or modifications of climatic or other physical factors of the environment have been carefully studied. When properly understood, these effects have moreover frequently been termed "physiological" as opposed to "pathological". With a broad definition of pathological this interpretation would be illogical. Nevertheless the student of fungous diseases of plants has been the chief plant pathologist. This is partially due to the fact that the disease-producing fungi are intimately associated with the structure of plants, and a proper study of the fungus has necessitated a thorough comprehension of its relation to the plant upon which it grows, the host. Plant diseases and plant pathology are, therefore, more or less synonymous with fungous diseases of plants, and the narrow use of the term plant pathology will on this account doubtless long persist." - Duggar. Fungous Diseases of Plants. pp. 93-94. 1909.

Disease is "any deviation from the normal structure or functions of plants or plant parts sufficient to threaten their life or impair their economic usefulness." - L. R. Jones.

B. Symptoms and Signs of Disease.

Stevens and Hall give the following list of symptoms:

"Every part of a plant - root, stem, leaf, flower, fruit, bark, wood, veins - is subject to disease, and the same disease may be manifest in many, even all, of these parts at once.

"Rot is perhaps the most common symptom of disease to be noted in any plant part. Rot is of many characters, - soft, wet, dry, hard, offensive or inoffensive of odor.

"Blight is a symptom often exhibited by leaves, roots, stems, flowers, or fruit. It indicates complete death of the part affected, may be local or general, and may or may not be followed by rot.

"Wilt of stems or leaves is caused usually by either a plugging, or other interruption, of the sap-carrying veins, or by some injury to the abosrbing root system.

"Spots of leaves, bark, or fruit may be caused by local blight, rot of tissue, imperfect coloration, or by local over-development or under-development of color.

"Scab in fruit, leaves, or bark is due to the growth of the causal parasite upon or near the surface, or to thickening of the outer layer or layers of tissue caused by the irritation of a parasite.

"Mildew upon any plant surface consists of a whitish powdery fungous growth.

"Burn is a general term applied to all cases where the leaves turn red or brown, especially if the edge first shows the symptom.

"Smut consists of a mass of spores, usually black and powdery. It is most common in the ovaries and other floral parts of the cereals.

"Rust should properly be applied only to cases where the special rust fungi (Uredinales) are present. Rusts usually show the spores in sori.

"Yellowing of leaves, due to diminution in green coloring matter, is a common symptom of disease.

"Chlorosis is a lack of proper green, a whitening of tissues which should be normally green.

"Canker consists of a roughening or splitting of the bark.

"In addition to the somewhat general characters accompanying diseases, it is necessary for purposes of diagnosis to note closely the detail characters of each sick part.

"In a spot the color of its margin and center; its border, whether sharp or indefinite; whether the same upon both upper and lower surfaces are important items to observe.

"In a rot these same details, also the texture, soft or hard, wet or dry, the odor, and taste are important.

"In the plant, as a whole, it is well to note whether the disease is local or general, progressive or stationary, spreading regularly or otherwise.

"Certain minute structures should be looked for upon rots, spots, cankers, or other diseased parts. Some of these, which may be recognized with the naked eye or a good hand lens, are:--

"Pycnidia or perithecia. - Small, nearly microscopic, covered sporiferous pustules on the surface of the diseased area.

"Acervuli. - Structures like pycnidia, but uncovered.

"Sori, or spore clusters.

"Hyphae. - Erect, hair-like; very nearly microscopic growths coming from the diseased area. Their presence upon a white background may often be recognized by the dirty ashen color which they lend to the spot.

"Cluster cup. - The cup-like sorus in which the spring spores of many rusts are borne.

"Sclerotia. - Small, hard bodies variously colored, but usually black; masses of compact fungous threads." - Stevens, F. L. and J. G. Hall. Diseases of Economic Plants. pp. 14-18. 1910.

A somewhat different classification of symptoms is found in the plant pathology manual used at Cornell University and quoted below:

"For field identification of diseases one must depend largely upon symptoms and signs. By symptoms is meant those changes induced in the diseased plant which distinguish it from the healthy. Signs of disease are incidental or experimental evidences of disease and not the direct results or expressions of the diseased conditions.....

"Symptoms are usually the expression of structural changes of one kind or another (histological or morphological). Diseases in plants are of three general types within each of which are exhibited a considerable variety of symptoms. These three types of disease with some of their more characteristic symptoms are:--

"NECROTIC DISEASES - those in which the most striking effect on the host is the death of the affected tissues resulting in such symptoms as:--

"Rot - the term applied when the killed tissues become discolored and decayed. If the tissues in such lesions are dry and firm it is called dry rot; if soft and mushy, soft rot; if firm or tough but very watery or soggy, wet rot; if white in

color, white rot; if black, black rot. The term rot, coupled with the name of the part or organ affected serves to designate a variety of symptoms such as, stem-rot, bud-rot, crown-rot, root-rot, heart-rot, foot-rot.

"Blight - the term applied when there is rapid killing of the affected parts often accompanied by wilting and withering of the foliage. This term coupled with the name of the host organs gives, twig-blight, blossom-blight, body-blight, leaf-blight, and the like.

"Wilt - the term applied where all or a portion of a plant becomes limp due to loss of turgor. Wilt differs from blight in that the causal factor does not directly affect the wilting or dying organs. The injury results from the activities of the causal factor usually in the vascular system somewhere below the wilting organs.

"Spot - the term used to designate necrotic areas, usually those in leaves, fruits and herbaceous stems. This term is used in numerous combinations to designate a variety of spot-symptoms as, leaf-spot, fruit-spot, pod-spot, and the like.

"Shot-hole - the term applied to limited necrotic spots on foliage where the dead tissue drops out leaving a hole. Peculiar largely to the foliage of peaches, plums and cherries.

"Damping-off - used to designate the symptom resulting from the rotting of the stems of seedlings at the base and the consequent falling-over of the tops. A form of stem-rot.

"Canker - the term applied to definitely delimited necrotic lesions in the bark of woody plants or the cortex of herbaceous stems; smooth or roughened, sunken or raised.

"HYPOPLASTIC DISEASES - those in which the most striking effect on the plant is a halting in some feature of its normal growth and development resulting in such symptoms as:--

"Dwarfing - the term applied in those cases where the plant or organ does not reach normal size. Special terms like, curly-dwarf, leaf-roll, spindling-sprouts, and little-peach, are but disease names used to designate peculiar forms of dwarfing.

"Chlorosis - used to designate the failure of or insufficient development of chlorophyl. Especially characteristic forms of chlorosis have been designated by such names as, mosaic, calico, frenching, and yellows.

"METAPLASTIC DISEASES - those in which the most striking effect of the disease is the overgrowth or overdevelopment of the affected tissues or organs. Stimulation of growth and development beyond the normal results in such symptoms as:--

"Hypertrophy - the term in its broadest sense to designate all abnormal overgrowths in size of diseased parts or organs. Among the specially designated forms of hypertrophy are, galls, knots, and tubercles, which are more or less globose

swellings of leaves, stems, fruits or roots resulting from the stimulating activities of such causal factors as insects, fungi, bacteria and mechanical injuries. Combinations with the names of the plant-organs affected give the terms, corwn-gall, root-gall, root-knots and root-tubercles.

"Witches' brooms - broom-like growths resulting from the dense fasiculation or clustering of branches due to the forcing of adventitious buds from or about the diseased tissues.

"Hairy root - abnormal root development of the same character and nature as witches' brooms on the limbs.

"Scab - definite areas on fruits, tubers and other organs usually due to injury followed by abnormal cork-development resulting in a rough raised or sunken spot.

"Curl - a term applied usually to overgrowths of leaves resulting in a thickening and fluting or puffing of the diseased areas, usually accompanied by abnormal coloration." - Whetzel, H. H., Lex. R. Hesler, Chas. T. Gregory and W. Howard Rankin. Laboratory Outlines in Plant Pathology. pp. 7-8. 1916.

C. Classification of plant diseases.

A great many different classifications of plant diseases have been suggested by various writers in the past and even yet not all are agreed upon the most satisfactory system of classification. There are several different bases on which a classification can be made and it would seem that the point of view or the use to which such classification is to be put should determine on which basis it should be made. The basis most commonly used is that of cause. Other bases which have been used are symptoms and host. If one were interested chiefly in the etiology of plant diseases, the logical basis on which to classify them would be that of the causal agent. If identification of diseases were the chief object in view, then one would be inclined to use the symptomologic basis. But if one had already become familiar with the different kinds of causal agents and with the different types of symptoms encountered in plant disease studies and if one were interested mainly in the diseases of certain crops, as potatoes or apples, then it might prove more convenient to group diseases under their respective hosts.

Following are several outlines of classification selected at random from different authors but grouped according to the basis on which they are made:

I. On basis of cause.

A. Tournefort's classification.

1. Diseases due to external causes.

2. " " " internal " .

---------Tournefort: Observations on the maladies of plants. 1705. (From Whetzel's History of Phytopathology. p. 26. 1918.)

B. Ward's classification.

"It is customary to classify the causes of disease in plants into two principal groups - (1) those due to the action of the non-living environment - soil, atmosphere, physical conditions such as temperature, light, etc.: and (2) those brought about by the activities of living organisms - plants and animals of various species." - Ward, H. Marshall. Diseases in Plants. pp. 99. 1901.

C. Hartig divides plant diseases into five classes as follows:

1. "Diseases induced by Phanerogams (seed plants).
2. Diseases induced by Cryptogams (spore plants).
3. Wounds.
4. Diseases due to unfavorable conditions of the soil.
5. Diseases due to unfavorable atmospheric conditions."
   - Hartig, Robert. The Diseases of Trees. p. 8. 1894.

D. Below is still another classification as suggested by Freeman:

"The diseases of plants and their causes may be grouped as follows:

1. Organic diseases, i.e., those caused by living organisms such as:

   a. Fungi.
   b. Bacteria.
   c. Slime molds.
   d. Insects and other animals.

2. Inorganic diseases, i.e., those due to other causes than living organisms:

   a. Unfavorable conditions of soil, etc.
   b. Unfavorable conditions of weather, etc."- Freeman, E.M. Minnesota Plant Diseases. p. 1. 1905.

E. Melchers (11), in 1915, suggested the following grouping of plant diseases:

1. Non-parasitic diseases.
2. Diseases of unknown origin.
3. Parasitic diseases.

F. The writer ventures to suggest the following as being more complete and up-to-date than any of the preceding:

1. Parasitic diseases.

   a. Caused by parasitic plants.

      (1) Caused by slime moulds,
      (2) Caused by bacteria,

(3) Caused by fungi,
(4) Caused by parasitic seed plants.

b. Caused by parasitic animals.

(1) Caused by eelworms.

2. Virus diseases (Infectious chloroses, etc.)

3. Non-parasitic diseases.

a. So-called "physiological" diseases.

4. Diseases of unknown origin.

II. On basis of symptoms.

A. Zallinger's classification.

1. Phlegmasiae, or inflamatory diseases.
2. Paralysis or debility.
3. Discharges or draining.
4. Cachexia, or bad constitution.
5. Chief defects of different organs.

--Zallinger, J. B. De morbis plantarum. 1773. (From Whetzel's History of Phytopathology. p. 28.)

B. Stevens.

In the Botanical Gazette for April, 1917, Stevens suggests the following classification for the parasitic diseases:

"Aside from the non-parasitic diseases, those caused by improper environment of soil, air, light, by abnormal hereditary tendencies, by unknown factors and by predatory animals (including insects), and considering only those known to be caused by parasitic fungi, there are certain groups of conditions which stand out strongly marked as being similar. It is of distinct advantage in studying, in teaching, and in devising and promulgating remedies, to recognize and define these categories. By their very similarity, certain diseases have gravitated together; for example, the vascular diseases, fungous or bacterial diseases, with plugging of the bundles, popularly and very properly called the 'wilts'.

"It is interesting to note that one of the most significant contributions along this line appeared in one of our elementary texts; significant, too, that this contribution should come from one not primarily interested in pathology. COULTER, in his Elementary studies in botany, gives us the conception of three general categories of plant diseases: (1) those in which the parasites kill the living cells; as pear blight, spot diseases, downy mildew, potato blight; (2) those in which the parasite does not kill the living cells, but lives in association with them, feeding upon their products; as rust, crown-gall, curl, black knot; (3) those in which the parasites invade the vessels and live in the sap; as cabbage, cucurbit, and mushroom wilts and wood rot.

"I have given some thought to this subject, and.....would present the following suggestions as a step toward a classification of plant diseases caused by fungi, separating them into the following categories:

"1. Wilt diseases due to mechanical stoppage of the vascular bundles by parasites. These may be called cases of embolism; for example, vascular diseases due to Ps. campestris, B. solanacearum, and Acrostolagmus.

"2. Disintegration of the xylem structures; for example, the various wood rots.....

"3. Diseases due to parasites wholly contained within the living protoplasm of the host cell. This is the strictest type of parasitism, and may appropriately be known as endocellular parasitism; for example, diseases due to Synchytrium.

"4. Diseases due to parasites which draw their nutriment from living cells by haustoria, which may be called endocellular haustorial parasitism; for example, diseases due to Phyllactinia, Peronospora, Albugo, and Plasmopara. In this group the conspicuous feature is the relatively large development of the haustorial surface as compared with the remainder of the internal mycelium.

"5. Diseases in which the live epidermal cells only are directly parasitized. These may be called cases of epidermitis, for example, diseases due to the Erysiphales (exclusive of Phyllactinia), Meliola.

"6. Diseases in which the parasite grows between the living host cells. Haustoria may be present, but if so they are not prominent, and the apparently dominant part of the absorptive system is the intercellular mycelium. This may be called intercellular mycosis; for example, rusts, Exoascales, Exobasidiales, and Cephaleurus.

"7. Diseases in which the host tissue is displaced or replaced by fungous masses. This may be called mycosclerosis; for example, diseases caused by Claviceps, Phyllachora, Rhytisma, and the smuts.

"8. Diseases of the type produced by Pseudomonas tumefaciens, which may be called tumor.

"9. Diseases in which the dominant feature is death of the host cells before they are actually invaded by the parasite. To these may be applied the term necrosis. Subdivision may be made on the basis of the part involved, as:

"9a. Cortical necrosis, in which the cortex chiefly is involved; for example, cankers caused by Sphaeropsis, B. amylovorus, and Endothia.

"9b. Parenchymal necrosis, in which chiefly the parenchyma is affected, including the greater number of the soft rots; for example, soft rots caused by B. carotovorus, Rhizopus, Penicillium, Phythiacysitis,

Rhizoctonia, Pythium, Phytophthora, Sclerotinia, Botrytis, Colletctrichum and Gleosporium.

"9c. Macular necrosis, in which necrosis is limited to spots, chiefly occurring in leaves. This is divided into (1) macular necrosis with abscission (the 'shot-hole' diseases caused, for example, by Cylindrosporium and Marssonia); (2) macular necrosis without abscission (chiefly the leaf spots, caused, for example, by Pseudopeziza, Entomosporium, Macrosporium, Lophioderma, Guignardia (phyllosticta), Ascohyta, Ramularia, Septoria, Diplodia, Cercospora, Colletotrichum, Gleosporium, Fusicladium, Cladosporium, and Alternaria.

"The following synopsis may make these categories and their interrelations clear.

"I. The parasite living in the sap or in cavities or parts devoid of living protoplasm:
(1) embolism;
(2) wood rots.

"II. The parasite for the major part of its life drawing its nutriment from host cells that are still living:
(3) endocellular parasitism;
(4) endocellular haustorial parasitism;
(5) epidermitis;
(6) intercellular mycosis;
(7) mycosclerosis;
(8) tumor.

"III. The parasite living within host cells or tissues which have recently been killed or partially disorganized by it:
(9) necrosis;

(9a) cortical necrosis;
(9b) parenchymal necrosis;
(9c) macular necrosis;

(9c') macular necrosis with abscission;
(9c'') macular necrossis without abscission."

- Stevens, F. L. Problems of Plant Pathology. The Botanical Gazette, 63: 297-306. April 1917.

C. Classification by Whetzel.

1. Necrotic diseases.
2. Hypoplastic diseases.
3. Metaplastic diseases.
--Adapted from Whetzel, H. H., et al. Laboratory outlines in plant pathology. pp. 7-8. 1916.

III. On basis of hosts.

In colleges and universities with which the writer is familiar it is customary to offer courses on the diseases of particular crops or groups of crops. For example, a course might be given especially for those interested in vegetable gardening. Such a course might be entitled: "Vegetables diseases" or "Diseases of vegetables". Likewise, other courses might be labeled "Fruit diseases", Diseases of Cane fruits", "Diseases of truck crops", etc. At the Oregon State Agricultural College the following courses in plant pathology are listed in the catalog. "Principles of Plant Pathology", "Fruit diseases", "Diseases of farm crops and vegetables", and "Forest Pathology". All of these courses, except the first, are based on the host classification principle. Each course is designed for a particular group of students who are specializing in horticulture, farm crops or forestry as the case might be. It should be mentioned that "Principles of Plant Pathology" is the beginning course in plant pathology and is pre-requisite for all the other courses. As might be expected the types of diseases studied in this course are classified on the basis of cause rather than hosts.

Which basis is best?

To the writer it seems logical that in the beginning course the diseases should be classified on the basis of cause. The most fundamental principle in the science of phytopathology is certainly the fact that the cause of a disease must be thoroughly understood before effective control measures can be applied intelligently. Then what is more reasonable than that causes should be accurately classified and each type of causal agent thoroughly mastered? After this fundamental knowledge has been acquired it is entirely permissible that the student should specialize on the diseases of any particular crops in which he may be especially interested.

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CHAPTER IV.

Methods of investigating plant diseases.

As a rule any very extensive and fundamental investigations of the parasitic plant diseases involve the growing of the organisms in pure culture and the making of artificial inoculations, or, in special cases, the latter operation only.

A great many fungi can be grown in pure culture on artificial media of one sort or another. Some common examples of this kind are: the brown-rot fungus, Sclerotinia cinerea, the apple anthracnose organism, Neofabraea malicorticis, the black-rot canker fungus, Physalospora cydoniae, the potato rot and wilt fungi, Fusarium and Verticillium, the peach blight fungus, Coryneum beijerinckii and the apple blotch organism, Phyllosticta solitaria.

On the other hand certain kinds of fungi are incapable of being cultured on a substratum other than the living host. Examples of such obligate parasites are the rusts, powdery mildews, and some of the downy mildews.

Culture media and apparatus.

Culture media may be divided into two general classes, liquid and solid.

Liquid media are more often used in the culture of bacteria than of fungi. Beef extract, or bouillon is the chief fluid medium used for the bacteria. Plant decoctions are useful in culturing fungi but the most convenient way in which they may be utilized is to use them in making solid media as described below. Milk is sometimes useful in culturing bacteria. Synthetic liquid media composed of various salts and other nutritive substances in proper proportions are necessary in certain physiological studies of pathogenic organisms.

Solid media are most commonly used for fungus cultures. They are of two general types, agar and pieces of plants. Agar is a substance resembling gelatin and is manufactured from certain species of seaweeds. The agar alone has no great nutritional value but is simply used to solidify the nutrient medium which usually consists of some plant decoction suitable for the growth of the fungus. A formula which works well for many common fungi is known as potato, glucose agar and consists of the following:

500 grams	potatoes
50 "	glucose
50 "	agar
2500 cc.	water.

Cook the potatoes in enough water so that when done and the water is strained off there will be 500 cc. of it.

Dissolve the glucose in 500 cc. of water.
Melt the agar in 1500 cc. of water.
Mix the three ingredients and sterilize in the autoclave at 15 pounds pressure for 15 minutes. Pour into test tubes, about 10 cc. per tube, plug the tubes with cotton and sterilize again for 15 minutes. Place the tubes in a slanting position until the agar cools and hardens.

Pieces of plants are sometimes used without the addition of any other substance, nutritional or otherwise. For example, potatoes or carrots may be cut into suitable pieces, placed in test tubes, plugged and sterilized in the usual way. Herbaceous or woody stems may be used in the same way. For culturing some of the wilt organisms such as Fusarium and Verticillium, sweet-clover stems are very satisfactory. Substances such as rice and corn-meal are sometimes used.

The apparatus needed consists essentially of test tubes, petridishes and flasks to hold the medium and of appliances for cooking and sterilizing it. Gas burners, electric hot-plates and steam from the heating plant may be utilized to furnish the necessary heat. Granite-ware or aluminum cooking utensils should be available. Steam sterilizers and autoclaves are desirable for thorough work. Cotton batting for plugging the tubes and cheese cloth and cotton for filtering the hot agar are necessary. Wire baskets for holding the tubes are desirable. For more detailed information on these topics see references (1) and (2) at the end of this chapter.

Isolations and inoculations.

There are several different methods of isolating an organism in order that it may be grown in pure culture. The method used depends upon the nature of the fungus, stage present on the diseased specimen, nature of the substrate, etc. In some cases such as rotted fruits, bark cankers and vascular parasites in tubers, the organism can be easily isolated by carefully removing, by means of sterile scalpels or needles, small bits of the diseased tissue from beneath the surface and planting these bits on the surface of the agar in a tube or petri dish. In this manner hyphae of the fungus, growing in the diseased tissue are transplanted along with the tissue and these mycelial threads soon grow out over the agar. Transfers can then be made by removing bits of the mycelium from the margin of the spreading growth and transplanting to new tubes.

In case the fungus is sporulating a quantity of spores may be shaken up in a test tube containing sterile water and the isolations made as described by Duggar (1) in the following paragraphs:

"In making cultures with a view of isolating, or separating out various microscopic organisms, the poured-plate (Petri dish) method is now almost exclusively employed. Such cultures may be called isolation or separation cultures, the use of the old term dilution culture being less desirable.

"Materials needed. In order to make these isolation cultures, one requires nutrient media and apparatus more or less as follows:

"Sterilized Petri dishes, of about 100 mm. diameter; test tubes containing about 10 cc. of sterile agar agar; a few very short test tubes without agar; a platinum needle; a beaker, or tumbler, with some cotton in it, to hold the tubes; a thermometer; and some boiling water. The agar in the tubes is melted, either in the steam sterilizer or in an open casserole of boiling water with cloth or cotton at the bottom. In ordinary culture work, as well as in bacteriological work, three tubes, and consequently three Petri dishes, constitute an isolation series. Three tubes of melted agar are placed in the beaker, which is filled with water at from 40° - 42°C.; and this temperature, which is above the point of solidification of agar, should be maintained throughout the period of culture by the addition of hot water when necessary.

"The method.- In making the cultures the procedure may be as follows: Some of the spores or bits of the material from which cultures are desired are diffused in a drop of sterile water placed in one of the short test tubes (or a flamed slide will suffice). The three tubes in the beaker are denoted 1, 2, and 3 respectively, and may be so marked with a wax pencil. The short tube containing the spores and tube No. 1 are taken between the thumb and index finger and the index and middle fingers respectively, and held almost horizontal, palm upward, the plugs having been previously removed and held between the spaces of the remaining fingers. The flamed but cold platinum needle, provided with a loop at the tip, is taken in the right hand, dipped into the drop of spores, and then into the agar of No. 1 and mixed. This may be repeated several times, unless the spores in the drop are very numerous. No. 1 is now placed in the former position of the short tube, and No. 2 in the place of No. 1. The process is repeated with this combination, and, finally, with Nos. 2 and 3 the contents of each tube is then poured into a corresponding Petri dish upon the top of which number, date, and any description desired may be inscribed with the wax pencil."

In isolating a bacterial organism from a diseased plant a bit of the infested tissue is crushed thoroughly in a tube of sterile water by means of a sterile glass rod or other suitable instrument in order to release large numbers of the bacteria in the water. Then the further procedure is exactly as described by Duggar above for spore isolations.

If these cultures are made sufficiently dilute it will be possible to pick out colonies on the plates which have arisen from a single spore or a single bacterium and subcultures can then be made from these colonies with assurance of getting a pure culture of the organism.

Inoculations are easily made after the organism has been secured in culture. If the organism is one which cannot enter the host through the unbroken epidermis, the inoculation is usually made by cutting through the epidermis with a sterile scalpel or puncturing it with a needle. Then either spores or bits of the mycelium are inserted into the opening and some device is used to prevent too rapid drying out of the wound. On the other hand, if the organism is able to enter without any wound in the surface of the host, inoculation may be accomplished by simply placing some spores on the surface of the host, by means of such instrument as a camel's hair brush, or they may be sprayed on with an atomizer. In this type of inoculation it is usually necessary to spray the inoculated surface thoroughly with water and retain a high degree of humidity by keeping the inoculated plant in a moist chamber or by some other effective device. The rusts are good examples of fungi

with which the latter type of inoculation is effective. With the rusts no artificial cultures are possible or necessary. Fresh spores can simply be taken direct from one plant and placed upon another as described above.

Some uses of pure cultures and artificial inoculations.

There are many different reasons for making inoculations. Some of the purposes for which the plant pathologist may make artificial infections are, to determine: the cause of the disease, conditions for growth of the organism, susceptibility of varieties, life history relationships, biological races, conditions for development of different stages, and methods of control.

a. To determine the causal relation of a particular organism.

An example will serve to illustrate this point. The causal organism of apple anthracnose (Neofabraea malicorticis) can easily be isolated by the tissue culture methods previously described, grown in pure culture and re-inoculated into a healthy tree by cutting the bark and inserting a bit of the culture, with the result that in due time a typical canker will appear on the tree.

In this connection the plant pathologist should keep constantly in mind that the rules of proof, which Kock formulated for use in studying disease-producing bacteria, and known to the bacteriologist as "Koch's Postulates", are just as applicable to the study of fungous and bacterial diseases of plants as to the work of the bacteriologist and physician. Park and Williams (3) state these rules as follows: "(1) A specific organism always associated with a disease, (2) when isolated in pure culture and (3) inoculated into a healthy susceptible animal always produces the disease, and (4) may be obtained again in pure culture."

Duggar (1) in discussing the applicability of these rules to plant pathological work, expresses them as follows:

"a. Under diverse conditions the fungus must be constantly and abundantly associated with the disease, or pathological state.

"b. The organism should be grown in pure cultures, when possible, and its differential characteristics well studied.

"c. The characteristic disease should be produced by infection experiments with a pure culture.

"d. The fungus associated with the disease induced should be identified as the one originally separated, and any abnormalities of host should likewise correspond." - Duggar, Fungous Diseases of Plants. pages 76-77. 1909.

b. To determine the conditions under which an organism is most virulent.

It is a well established fact that the environment plays a very important part in determining the prevalence of any disease. The soil and climatic or weather conditions must be taken into consideration in any intensive study of parasitism. It is well known that acidity and alkalinity of the soil determine the ability of

certain organisms to become serious pathogens. The temperature and moisture content of the soil as well as of the air are important factors, the fluctuations of which, favor or inhibit, as the case may be, the development of disease organisms. Artificial inoculation experiments are of great aid in studying the influence of such conditions upon the activity of the organism. The influence of environment upon plant disease will be discussed in more detail in Chapter V.

c. To determine the susceptibility of varieties, species, etc. to a specific organism.

It is often desirable to determine the range of pathogenicity of a particular organism. For example, it is desirable to know just what species of pine Ribes and Grossularia are susceptible to Cronartium ribicola, the cause of the White Pine Blister Rust. Rather than depend upon observations of natural infection, extending over a long period of time and a wide range of territory with no certainty as to the final conclusions, it is possible and desirable to gather together in one place all known species of the above mentioned hosts, and under the most favorable conditions, make artifical inoculations and thus determine in a relatively short time exactly which species are susceptible to attack and to what extent.

d. To determine the life history relationships of the different stages of an organism.

Many fungi have two or more stages in their life cycle. These stages usually do not occur simultaneously but follow each other in rotation. In many cases the different stages may occur on different parts of the same host or even on alternating hosts. The brown-rot fungus has two spore forms, the conidial (Monilia) stage and the perfect or ascospore stage. The conidial stage appears on recently rotted fruits, on blighted blossoms and spurs and on branch cankers. The ascospore stage develops from the sclerotia of old mummified fruits that have lain on the ground for one or more seasons. Before these two spore forms could be definitely ascribed to the same species beyond the shadow of a doubt, it was necessary to grow the fungus in pure culture and by inoculating the host to produce the spore stages again. For example, a pure culture could be grown from a single ascospore. Upon inoculating a fruit from this culture and allowing the fruit to rot under proper conditions a crop of conidiospores would be produced. Then if the rotted fruit were planted out on the ground and allowed to remain under favorable conditions for the requisite period of time the perfect or ascospore stage would appear. This same procedure might be carried out by starting with a single conidiospore and the same results obtained. After all these steps have been successfully carried out there can no longer be any doubt as to the relationship of the two stages.

Another good illustration of this point is the classical example of De Bary's work with the black stem rust of wheat which has several spore stages on two different hosts. While this rust fungus cannot be grown in pure culture in a test tube as can the brown rot fungus, yet it is possible to inoculate wheat plants with aeciospores from the barberry and produce the urediniospores and teliospores on the wheat, or to inoculate barberry bushes with basidiospores from the telial stage and produce the aecial stage on the barberry.

e. To determine if an accepted species can be segregated into biologic forms.

One of the best illustrations of the work that has been done on the so-called "Physiological species", or biologic races or forms, is that done by Stakman (4) and others (5, 6) on stem rust (Puccinia graminis). This species has been divided into three chief races, namely Puccinia graminis tritici on wheat, Puccinia graminis secalis on rye, and Puccinia graminis avenae on oats. The form tritici has again been subdivided into several other forms. All of this segregation has been accomplished by careful inoculation work. It has been found that some species or varieties of grains are susceptible to certain races of the fungus and resistant or immune to other forms. Stakman and his co-workers have selected a dozen varieties of wheat which they have determined to be most useful in differentiating the known biologic forms of Puccinia graminis tritici and have designated these as "differential hosts".

f. To test certain methods of control.

In some cases experimental work on plant disease control can be much more readily and accurately carried out if the host can be artificially inoculated with the disease organism. Reimer (7) performed extensive tests with wound disinfectants for fire-blight by first inoculating a freshly made wound with a pure culture of the fire-blight organism, Bacillus amylovorus, and immediately applying the disinfectant to the surface of the wound.

A type of inoculation is often used in experimental seed treatment for the control of wheat smut. A quantity of wheat is thoroughly dusted with smut spores then divided into two parts. One part is treated with the fungicide to be tested while the other portion is left untreated and planted as a check.

g. To determine the conditions under which the different stages of a fungus will develop.

In some cases the perfect stage of a fungus is rarely found while the conidial stage may appear in abundance every year. In such cases it would seem that the stage which occurs only rarely is very sensitive to environmental or other conditions and shows up only under just the right combination of circumstances. It is often desirable to determine what these favorable or unfavorable conditions are and the surest way is by means of artificial culture work. Leonian (8) found that he could induce or prevent the formation of both pycnidia and perithecia in Valsa leucostoma by varying the ingredients in the culture medium on which the fungus was grown.

Records.

In work of this kind it is absolutely essential to accuracy that careful and complete notes be taken. The records should include descriptions of the lesions from which the culture is taken, characters of the growth in culture, source of the material and date collected, date of culturing and of any transfers, the kind of culture medium used, rate of growth and conditions under which cultures are grown. Drawings and photographs are very useful in certain phases of the records.

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CHAPTER V.

Relation of Plant Diseases to Environment.

The environment of plants is composed of two chief factors (a) the soil, and (b) climatic and weather conditions. The non-parasitic diseases, as, for example, Bitter-pit of apples and Point-rot of tomatoes are due very largely, if not entirely, to these environmental factors. In case of the parasitic diseases, the life activities of both the host and the parasite are profoundly influenced by their environment.

The soil.

The chief factors of soil environment which affect the growth and development of plants, both host and parasite, are the physical condition of the soil, its chemical composition, and its biological condition, that is, its floral and faunal content.

Important items in the physical make-up of the soil are the size and shape of the constituent particles and its looseness or compactness, which conditions in turn determine the water-holding capacity and the degree of aeration of the soil. All of these factors have a decided influence upon the growth of plant life, of whatever kind, in the soil. Naturally this influence is reflected in the diseases of plants, both non-parasitic and parasitic.

The chemical reaction of the soil has a direct relation to many plant diseases. There are some striking illustrations of this relation to be found in the behavior of certain parasitic diseases. One of the most common examples is the common scab of potato. Nearly all workers agree that this disease is apt to be more prevalent in an alkaline soil. In experimental work the correction of this alkalinity has lessened the disease. In contrast with this case it has been shown that an acid soil is favorable for the development of the cabbage club-root organism, Plasmodiophora brassicae. A commonly recommended control measure for this trouble is the application of lime to the soil to correct the acid reaction and thus bring about a soil condition which is unfavorable to the growth of the club-root organism.

Sherwood (1) conducted experiments to determine the effect of soil reaction on the development of Fusarium wilt of tomato seedlings. He arranged a series of soils from strongly acid to alkaline such that the exact reaction of each was accurately known. He found that the highest percentage of wilt occurred in the most acid soils of the series and the amount of wilt decreased as the hydrogen-ion concentration of the soils decreased, within certain limits.

The flora and fauna of the soil, especially the microscopic plant life, fungous and bacterial, are of utmost importance to the plant pathologist. It is common knowledge to everyone who has studied botany or bacteriology to any extent, that certain organisms of the soil are essential to the vigorous growth of crops.

Special reference may be made here to the bacterial organisms concerned in the nitrogen cycle so essential to plant nutrition. But the plant pathologist is more vitally interested in harmful micro-organisms of the soil. Some soils become so thoroughly contaminated with the disease germs of certain crops that it is no longer possible to grow these crops profitably in such soils. When a soil gets into this condition it is some times spoken of as "sick soil". (For a more complete discussion of "sick soil" conditions see chapter X).

Climate and weather.

Climate and weather undoubtedly determine to a very great extent the seriousness and even the existence of plant diseases, both parasitic and non-parasitic. The most important factors here are the temperature of the soil and air, and the moisture content of these elements of the environment. The temperature and moisture of the soil and air affect spore germination, infection, and development of the disease. They also affect the vigor of the host which in time is reflected in the virulence of the parasite.

Discussions of plant diseases in ancient and mediaeval history are full of allusions to the influence of the weather upon certain maladies. While it is true that the exact manner in which weather did influence diseases was not well understood in early times, yet it is significant that people in those days were convinced that the weather was responsible in some way or other.

Present day plant pathologists are just as certain that weather conditions play an important part in determining the prevalence of diseases as illustrated by the following passages from "The Plant Disease Reporter" issued by "The Plant Diseases Survey", Volume 8, Number 1, June 15, 1924:

"The unusual weather conditions that have prevailed this season deserve especial mention in any report of the plant disease situation. In general it has been unusually cold in states east of the Rocky Mountains and unusually wet for the most part east of the Mississippi River. On the other hand, west of the Rockies, drouth and hot weather have prevailed.....

"These unusual conditions....., especially the excess rainfall in the East, are bound to affect profoundly the plant diseases of the year. Already an epiphytotic of sycamore blight (Gnomonia veneta) has appeared and apple leafspot (Physalospora) is unusually abundant in some sections. On the other hand certain other diseases are being delayed in their appearance and may prove much less conspicuous than usual."

The literature on peach leaf-curl contains numerous references to the effect of the early spring weather on the prevalence of this disease. In 1900, Pierce (2) gave good reasons for suspecting that a cold, wet spring favored leaf-curl. He thought that such conditions favored the growth of the leaf-curl fungus, Exoascus, and made the tissues of the peach more susceptible to attack.

While the above statements are more or less general there is not lacking an abundance of specific evidence as to the effect of climatic and weather conditions upon plant diseases. During recent years a great deal of experimentation has been done on specific problems connected with the influence of soil and air temperature and moisture upon the growth of disease organisms and their ability to become virulent parasites. A few examples of this type of work will serve to emphasize the importance of these ecological factors in a study of plant diseases.

Jones (3), in 1917, expressed a growing conviction that plant pathologists will have to give more and more attention to the ecology of plant diseases. He called attention to a considerable amount of work that had been done in the last few years on the effect of temperature and moisture on plant diseases and suggested that certain soil organisms such as the Fusaria lend themselves to studies of this kind because soil temperatures and moistures are more easily controlled under experiment.

Jones, McKinney and Fellows (4), working on the influence of soil temperature on potato scab, under controlled conditions in the greenhouse, reported that the scab organism is favored by a relatively high temperature (about 22 degrees Centigrade) while the potato plant itself grows best at a relatively low temperature.

Richards (5) states that the potato rhizoctonia organism, Corticium vagum, does its greatest damage at a soil temperature between 15 and 21 degrees Centigrade with an optimum of about 18 degrees. The severity of the attack decreased rapidly above 21 degrees until at 24 the fungus proved to be of minor parasitic importance and at 27 or above few typical lesions occurred. He found that 18 degrees was also the optimum for host development. The same author (6) describes in a later article another piece of work with the same organism, Corticium vagum, but on other hosts, the pea and bean. He found that the organism did greatest damage to both these hosts at an optimum soil temperature of about 18 degrees Centigrade, while the pea plant itself did best at a temperature of 18 to 21 and the bean at 24 to 30. Thus it will be noticed that Corticium vagum has a constant optimum temperature of 18 degrees Centigrade, regardless of whether this temperature is optimum for the host. Richard's work would seem to indicate that the potato and pea are most susceptible to attack by Corticium vagum when growing under optimum soil temperature conditions for their own development, whereas the bean is most susceptible at temperatures below its optimum. Does this mean that the pathogenicity of Corticium vagum is a law unto itself and that the vigor of the host has nothing to do with it? In their work on potato scab, Jones, McKinney and Fellows (4) state that: "The immediate relation of temperature to the development of scab seems to be more closely correlated with its influence upon tuber development than with that upon the growth of the parasite."

Clayton (7) worked on the Fusarium wilt of tomato under greenhouse conditions where both soil and air temperatures were controlled. In only two of the nine combinations of soil and air temperatures which he used did the disease make rapid development. These favorable combinations were: (a) both air and soil at 27 degrees Centigrade, and (b) air at 33 and soil at 27. When the soil was too cool, 17 degrees, or too warm, 35 degrees, the disease did not make any progress, even with the air at the optimum. When the air was too cool, 17 degrees, and the soil

ptimum, 27 degrees, heavy infection occurred in the root and basal part of the tem but the plants grew thriftily and showed no signs of disease above ground.

Clayton (8) also carried on some soil moisture experiments at the same time hat he was making the temperature studies noted above. Part of his summary reads s follows:

"The plants growing in soil with a low moisture content, 13 to 19 percent, ere very resistant to the disease.

"The plants growing in soil which was kept saturated were immune to attack.

"In general it was found that any moisture shortage sufficiently severe to heck the vegetative vigor of the host checked the disease proportionally.

"When rapidly growing plants held at a temperature below 20 degrees Centigrade ere brought into a temperature favoring the diseases (25° - 30° C.) they were soon ttacked by the wilt. However, if the soil was allowed to dry out as soon as the lants were placed at the warm temperature, the appearance of the wilt was very uch delayed. Thus, rapidly growing succulent plants, which had been susceptible o the disease, were made disease-resistant by allowing the soil to become very dry.

"Plants growing in soil with a very low moisture content lost their disease esistance if a rapid, vegetative type of growth was induced by the addition of ufficient water to keep the soil moist.

"Plants growing in saturated soil were immune to attack, but if the moisture ontent were lowered the disease soon developed.

"In a study of the influence of soil temperature and moisture on the develop- ent of the seedling-blight of wheat and corn caused by Gibberella saubinettii, ickson (9), found that the wheat plant develops best at a soil temperature of 16 o 20 Centigrade for spring wheat and 12 to 16 for winter wheat. The maize plant s favored by a temperature of 24 to 28. The seedling-blight disease develops est on wheat at a temperature of 12 to 28, and on corn at 8 to 20. It will be oticed that the range for the development of the disease on wheat is higher than he range for the host, while on corn the disease is favored by a temperature lower han the optimum for the host plant. Dickson further states that low soil moisture avors infection at all temperatures and at low temperatures may be the factor etermining infection. He checked his greenhouse work against field experiments nd found that sowing spring wheat early and winter wheat late checked the blight nd that planting corn late was also effective in lessening the injury from this isease.

Hungerford (10) states that experimentally he secured the highest percentage f bunt infection in wheat at a soil temperature of 9 to 12 degrees Centigrade and moisture content of 22 per cent.

Lauritzen and Harter (11) found that the percentage of infection of sweet otatoes by Rhizopus varies greatly with the relative humidity. Only a very small ercentage became infected at relative humidities of 94 to 98 per cent at temper- tures of 22.5 to 24 degrees Centigrade. At a humidity of 72 to 84 almost 100 per

cent of infection occurred. At humidities of 59 to 63 a great decrease in per cent of infection takes place and at 49-52 per cent humidity, only 20 per cent of infection occurred.

Non-parasitic diseases.

It is the general opinion that most, if not all, of the well-known non-parasitic diseases are due largely, if not entirely, to the environment. While there may not be general agreement as to the exact manner in which such diseases are produced it is conceded that moisture, temperature and soil, singly or in combination, are responsible for these troubles. For example, many specific theories have been advanced to account for Bitterpit in apples. The details of these theories differ but all of them agree on one point, namely, that some disturbance of the water balance in the plant causes the trouble. Cork and drouth spot are also attributed to a disturbed water balance. Point rot of tomato is another disease due to the same cause. It can readily be seen that weather conditions play an important part in diseases of this kind but it is not difficult to conceive that the physical condition of the soil might also be a factor in some cases mentioned above. In cases such as apple scald ventilation plays an important part. Improper temperatures are largely responsible for black-heart of potatoes, though good ventilation is also desirable in avoiding this trouble.

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CHAPTER VI.

Plant disease control: general statement.

As noted in Chapter I, history records that man has always manifested as much interest in the control of plant diseases as in their cause, in some cases perhaps more. In the early days the remedies recommended were necessarily impirical since practically nothing was known of the cause of disease in the great majority of cases. Even today we are using many control methods or devices that had more or less of an impirical origin, however much they may have been modified and adapted in recent years in accordance with our increased knowledge of the cause of the disease. With the aquisition of more and more accurate knowledge about the nature and cause of diseases we have worked out a multitude of methods and practices to meet the special need for combating any particular disease.

It would be difficult to compile a complete list giving all the different methods with all their different modifications that have been devised to control all the different diseases with which the agriculturist has to contend. Some writers have tried to generalize and condense all control measures under a few heads while others have attempted to give a more detailed list of remedial measures.

Below are lists of preventive measures which have been suggested by different authors. It will be noted that nearly all of them apply to parasitic troubles.

(a). In his "Fungous Diseases of Plants", pages 85-87, Duggar discusses methods of control under four heads, namely, (1) Resistant varieties, (2) Seed selection, (3) Crop Rotation, and (4) The application of fungicides.

(b). Stevens (2) mentions thirteen different methods of prevention as follows:

"1. Killing the causal organism as it rests upon the seed.- Examples: oat or wheat smut, cabbage black-rot.....

"2. Killing superficial fungi by applications upon the green parts of the plant.- Examples: powdery-mildew upon grape, gooseberry or rose.....

"3. Killing superficial fungi hibernating upon the bark of the dormant plant or plant supports.- Examples: apple hypochnose, peach curl.....

"4. The use of protective sprays or dusts.- Examples: grape black-rot, apple scab.....

"5. Excision of the affected parts.- Examples: Ash white-rot.....

"6. Removal and destruction of diseased twigs, leaves, or fruit.- Examples: fire-blight, peach brown-rot.....

"7. Removal, in whole or in part, of complementary hosts.- Examples: apple rust, wheat rust.....

"8. Avoidance of disease-bearing material or material favoring disease-- Infection may reach hay through sick melong vines (melon wilt), or manure may be contaminated by infected plant parts (potato scab, cabbage rot, melon wilt, etc.).....

"9. Prevention of wound infection.- Examples: heart-rots, sap-rots, cankers, fruit-rots.....

"10. Avoidance of susceptible varieties; selection of resistant varieties....

"11. Avoidance of disease-infested localities.....

"12. The practice of crop rotation.....

"13. Avoidance of practices that aid in dissemination of the parasite.- Examples: bean pod-spot, tomato leaf-spot."- Stevens, F. L. Diseases of Economic plants. (Revised Edition). pp. 14-18. 1921.

(c). Whetzel (3) and his co-authors have generalized to the extent of listing ll possible control measures under four main heads, namely, (1) exclusion, 2) eradication, (3) protection, and (4) immunization.

(d). The control measures listed below are classified according to the type f disease (i.e. parasitic, non-parasitic, virus) for which the measures are ecommended. Examples of one or more diseases are given after the various methods, llustrating the kind of diseases to which the different control measures are pplicable.

I. Control of parasitic diseases.

1. Use of fungicides.

a. Applied to the host.

(1) Spraying. For example, apple scab.
(2) Dusting; e.g., Powdery mildew of grape.
(3) Disinfecting seed or other propagating stock; e.g., wheat smut, potato rhizoctonia.
(4) Disinfecting wounds; e.g., Fire-blight, wood rots.

b. Applied to the environment.

(1) Soil sterlization; e.g., nemas.
(2) Sterlization of tools; e.g., Fire-blight.
(3) Disinfection of containers, carriers, storage quarters; e.g., wheat smut, potato dry rot.

2. Selection of seed or other propagating stock; e.g., bean anthracnose, potato scab.

3. Crop rotation; e.g., Soil organisms as Fusarium, Rhizoctonia.

4. Surgery (cutting out diseased parts); e.g., European canker, Fire-blight.

5. Roguing (uprooting and removal of diseased plants); e.g., Fusarium wilt and black-leg of potatoes.

6. Removal of alternate or complementary host; e.g., Stem rust of wheat, white pine blister rust.

7. Removal of weed hosts; e.g., wild hawthorne and service berry hosts of Fire-blight.

8. Sanitation (Destruction of diseased plants or parts of plants); e.g., Fire-blight prunings, brown-rot mummies.

9. Changing soil reaction; e.g., Liming for cabbage club-root.

10. Quarantine and inspection; e.g., White pine blister rust, potato wart.

11. Resistance and immunity; e.g., varieties of wheat resistant to smut, of cabbage to yellows, of asparagus to rust.

12. Insecticides and insect repellants (Some insects carry disease germs); e.g., Fire-blight.

II. Control of virus diseases.

1. Use of disease-free seed or other propagating stock; e.g., Mosaic-free seed potatoes; bramble fruit transplants.

2. Insect control; e.g., Aphids transmit potato mosaic.

3. Eradication of weed hosts; e.g., Tomato mosaic hibernates in horse nettles and ground cherries; cucumber mosaic in milk weed.

III. Control of non-parasitic diseases.

1. Modifying the environmental factors.

a. Physical condition of the soil.

b. Moisture supply; e.g., Bitter-pit of apple.

c. Temperature; e.g., Blackheart of potato.

d. Ventilation; e.g., Apple scald.

A complete and detailed discussion of all these methods and devices cannot be
en for lack of space but several of the more important phases of disease control
discussed at some length in the following Chapters.

References.

1) Duggar, B. M. Fungous Diseases of Plants. 1909.

2) Stevens, F. L. Diseases of Economic Plants (Revised Edition) 1921.

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CHAPTER VII.

Plant Disease Control (Continued): Fungicides.

The term "fungicide" as here used is construed to mean any agent of whatever nature that is applied either to the plant or plant parts or to the environment of the plant, such as soil, tools, containers, carriers, ware-houses, etc., for the purpose of disinfecting the plant or plant parts, or the environment, or for the purpose of protecting the plant against infection.

Fungicides may be classified on two bases; namely, (1) nature of the fungicide, and, (2) purpose for which used.

I. Classification of fungicides on basis of nature or composition.

A. Chemicals.

1. Copper-containing fungicides.

a. Copper sulfate.

(1) Dry dust.
(2) In solution.

b. Copper sulphate plus lime.

(1) Bordeaux mixture.
(2) Bordeaux paste.
(3) Copper-lime dust.
(4) Copper sulphate dip plus lime-water bath.

c. Copper sulphate plus sodium carbonate (Sal soda)

(1) Burgundy mixture.

d. Copper carbonate.

(1) Dust.
(2) Ammoniacal copper carbonate

e. Copper acetate.

2. Sulfur fungicides.

a. Lime-sulfur.
b. Commercial dry lime-sulfur,
c. Self-boiled lime-sulfur.
d. Wettable sulfur (Sulfur paste)
e. Oregon cold-mix lime and sulfur.
f. New Jersey dry-mix sulfur lime.
g. Sulfur dust.
h. Sulfur-lead arsenate dust.

3. Iron sulphate (Not good fungicide)

    a. With lime sulfur (Iron sulphide)
    b. With Bordeaux mixture (Iron hydroxide)

4. Potassium sulphide.
5. Formaldehyde.
6. Mercuric Chloride (Corrosive sublimate)
7. " Cyanide.
8. Organic-mercury compounds.

    a. "Uspulun" (Chlorphenol-mercury)
    b. "Germisan"
    c. "Semesan"

9. Creosote
10. Sulfuric acid.

B. Heat.

1. Hot water.
2. Steam
3. Dry heat (hot air).
4. Firing

II. Classification of fungicides on basis of purpose for which used.

A. Fungicides used to protect the host from infection.

1. Applied to the growing or dormant plant.

    a. Sprays

        (1) Bordeaux mixture; protection against apple anthracnose, peach blight, late blight of potato, etc.
        (2) Burgundy mixture: substitute for Bordeaux.
        (3) Ammoniacal copper carbonate: substitute for Bordeaux.
        (4) Lime-sulfur: protection against apple scab, etc.
        (5) Self-boiled lime-sulfur: protection against brown-rot of peach, etc.

    b. Dusts.

        (1) Sulfur dust: protection against apple scab, powdery-mildew, etc.
        (2) Copper-lime dust: protection against potato late-blight, apple scab, etc.

2. Applied to wounds.

    a. Air-porous dressings.

(1) Bordeaux paste: protection against wood-rotting fungi.

b. Air-tight dressings (Not fungicide in strict sense).

(1) Coal tar, asphaltum, white-lead, grafting wax: protection against wood rots.

3. Wood preservatives.

a. Creosote: protection against decay organisms.
b. Paints: (Not fungicidal but keep wood dry and thus prevent growth of decay organisms).

B. Fungicides used to disinfect the host or environment.

1. Applied to seed or propagating parts.

a. Liquid dips or steeps.

(1) Copper sulfate: disinfection against grain smuts.
(2) Formaldehyde: disinfection against grain smuts.
(3) Corrosive sublimate: disinfection for potato diseases.

b. Dusts.

(1) Copper carbonate: disinfection of seed wheat for stinking smut.

c. Heat.

(1) Hot water: disinfection of seed wheat and barley for loose smut.

2. Applied to the environment.

a. Soil disinfectants.

(1) Heat.

(a) Hot water or steam: disinfection for eelworms, damping-off fungi, etc.,

(2) Chemicals.

(a) Formaldehyde, copper sulfate, sulphuric acid: disinfection against "sick Soil" organisms.

b. Tool disinfectants.

(1) Corrosive sublimate: against fire-blight.
(2) Formaldehyde.
(3) Heat.

c. Disinfectants for containers, carriers, storage quarters, etc.

(1) Formaldehyde: disinfection of bags for smut.
(2) Copper sulphate: " of potato bins for rot organisms.
(3) Heat

A. Chemicals.

1. Copper-containing fungicides.

As noted in Chapter I the use of copper in the form of copper sulphate (blue stone) was practiced at an early date. Prevost used it to disinfect seeds in 1807. The persistant and continued used of copper fungicides, however, dates from the discovery of Bordeaux mixture by Millardet about 1883. Copper sulphate still remains the most important and most extensively used compound of copper in the treatment of fungous diseases of plants, but it is not the only copper fungicide used. Copper carbonate is forging to the front in recent years, particularly in the treatment of seed wheat for stinking smut. It is also sometimes used in making a substitute for Bordeaux mixture.

Copper sulphate.

Copper sulphate alone is quite commonly used as a disinfectant for seed or for containers, storage quarters, etc. It is customary to use it in solution for these purposes although in some cases attempts have been made to use it in dry or powdered form. For the treatment of seed wheat for smut the following formula is commonly used:

Copper sulphate (bluestone) ---------- 1.pound.
Water ---------- 5 gallons.
(1 pound of salt is sometimes added)
A lime bath is usually given the seed after this treatment.

A dust mixture of equal parts of copper sulfate and air-slaked lime has been used as a seed disinfectant for bunt of wheat with poor success.

For disinfecting potato bins for rots the following formula is recommended:

Copper sulphate ---------- 1 pound.
Water ----------10 gallons.

It may be said that copper sulphate has not given perfect satisfaction when used for the above purposes, especially in treating seed wheat, and it seems probable that it will ultimately be replaced by more satisfactory fungicides, some of which will be discussed later.

A solution of copper sulphate in water at the rate of 2 to 5 pounds per 50 gallons of water is sometimes used as a spray. It is safe only on dormant trees. It has been used with some success for peach leaf curl.

Bordeaux mixture.

Bordeaux mixture is one of the two most important sprays in use at the present ime. For certain diseases it is much more effective than lime-sulphur, its rival. here a spray is needed which has the sticking and lasting qualities required to ive protection over a long period of time, as is the case with such diseases as orthwestern anthracnose of apple and Coryneum peach blight, nothing has yet been ound to equal Bordeaux mixture. Also in certain diseases such as late blight of otato Bordeaux gives much better results than lime-sulfur.

The ingredients of Bordeaux mixture are copper sulphate, lime and water. he varying proportions of these components give rise to the different formulas n use:

The 4 - 4 - 50 formula.

Copper sulphate	4 pounds.
Stone lime	4 pounds.
Water	50 gallons.

For spraying potatoes the strength is usually increased to 5-5-50 or 6-6-50.

For use on more delicate plants it is necessary to use a weaker spray, for xample, 2-4-50 or 3-6-50.

Other formulas may be used if advisable.

Directions for making Bordeaux.- In making Bordeaux mixture a solution of oth the bluestone and the lime should be made up separately. For example, if the -6-50 formula is to be used, dissolve 6 pounds of bluestone (copper sulphate) in 5 gallons of water. Bluestone dissolves very slowly in cold water. Use hot ater, or suspend the bluestone in a gunny sack from a stick placed across the top f an open wooden barrel so that the material is barely below the surface of the ater. (Caution: Do not dissolve copper sulphate in a metal vessel). Slake the ime in another vessel. Add the water slowly and when the lime is completely laked add enough water to bring up to 25 gallons. When ready to use pour these wo solutions together while stirring.

When large quantities of spray are needed it is better to make up larger uantities of more concentrated solutions of copper and lime. This may be done by .ssolving 50 pounds of copper sulphate in 50 gallons of water and slaking 50 ounds of quick-lime and making up to 50 gallons with water. This gives a stock olution of each containing one pound of bluestone or lime to the gallon. Then if, or example, 200 gallons of 4-4-50 spray are needed, take 16 gallons of the blue- tone solution and pour it into the tank after having filled the tank two-thirds ull of water. Stir thoroughly, then add 16 gallons of the lime solution which as been somewhat diluted. Finally complete filling the tank up to two hundred allons. This gives a two-hundred-gallon tank full of 4-4-50 Bordeaux. The con- ntrated solutions of copper sulphate and lime should never be mixed before luting as this gives a very inferior quality of spray material.

Sugar as a preservative.- Bordeaux mixture deteriorates very rapidly upon tanding. If for any reason a quantity of spray is made up and cannot be used ithin a few hours, it may be preserved in good condition for an indefinite time y adding a small amount of common sugar, 1 oz. for every 8 pounds of stone lime r 10 pounds of hydrated lime used in the spray.

Hydrated lime a substitute for stone lime.- Under some conditions it may be esirable to use hydrated lime instead of stone lime in making up Bordeaux. In uch case it is necessary to use 50 per cent more of the former than would be used f the latter. For example, to make 4-4-50 Bordeaux one must use 6 pounds of ydrated lime instead of the 4 pounds of stone lime for each 50 gallons of spray.

Bordeaux paste.

One of the best dressings that have been devised to protect tree wounds gainst infection by wood-rotting fungi is Bordeaux paste (15). This contains he same ingredients as Bordeaux mixture but with much less water in proportion o copper and lime. The usual formula follows:

Copper sulphate, 1½ pounds in 1 gallon of water.
Quick lime, 3 pounds slaked in 1 gallon of water.
Mix in equal parts.

This makes a paste which is applied to the wound in the same manner as white- ash. Caution: For dissolving the copper sulphate see directions under Bordeaux ixture.

Copper-lime dust.

In 1918 Sanders and Kelsall (2, p. 286) began some experimental work in Nova cotia on a type of copper dust for which they later claimed marked success. heir formula follows:

Dehydrated copper sulphate ----------12 pounds.
Arsenate of lime----------10 "
Hydrated lime----------78 "

In a two-year comparative test it was claimed that the copper-lime dust was qually as effective as Bordeaux for the control of late blight of potato.

Copper carbonate.

Powdered copper carbonate is rapidly coming into prominence as a disinfectant or bunt of wheat. It is used at the rate of 2 ounces of the dust per bushel of heat. One great advantage this dust has is that it does not reduce the stand as s so often the case with the formaldehyde and bluestone treatments.

Ammoniacal copper carbonate.

In spraying fruits nearing maturity with Bordeaux mixture an unsightly deposit is usually left on the fruit. In order to avoid this undesirable result the above spray was devised. It is not usually as effective as Bordeaux but in some cases it may be desirable to use it as the lesser of two evils.

Formula.

Copper carbonate	5 or 6 oz.
Ammonia	3 pts.
Water	50 gals.

To prepare this spray first dissolve the copper carbonate in the ammonia, then add the water.

Burgundy mixture.

This is another substitute for Bordeaux and may be used to avoid staining or undesirable deposits on fruit and foliage. The formula follows:

Copper sulphate	1 lb.
Sodium Carbonate (Sal soda)	1½ lbs.
Water	50 gals.

Dissolve each chemical separately as in making Bordeaux mixture. Make up the stock solutions at the rate of 1 pound to 1 gallon. Before mixing the two dilute the copper sulfate with the requisite amount of water, then add the sal soda solution.

2. Sulfur-containing fungicides.

Sulfur as a remedy for certain diseases, especially powdery mildews, has been known for over a century (1). In addition to its use in the dust form sulfur is combined with lime to make the well-known lime-sulfur sprays of which there are several variations.

Concentrated lime-sulfur.

Sulfur	2 lbs.
Quicklime (Stone lime)	1 lb.
Water	1 gal.

Lime-sulfur can be made up in any quantity according to need and facilities for making, using the ingredients in approximately the proportions of the above formula. To make 50 gallons of concentrate use:

Sulfur	100 lbs.
Quicklime	50 lbs.
Water	50 gals.

Small quantities may be made in a kettle over an open fire. In this case one as to use a slight excess of water to make up for loss by evaporation.

If facilities are available large quantities can best be made by steam cooking. pipe should be run from a steam boiler directly into the cooking tank and steam urned into the mixture.

The cooking should continue for about 45 minutes over the fire or about 30 inutes if steam is used. Let settle and draw off the clear liquid, discarding he sludge.

It is usually possible to purchase the concentrated solution ready for use. here this can be done it is for the grower to decide whether it is more convenient nd economical to purchase the commercial solution or to prepare it at home.

In any case before the spray is used it is necessary to determine the strength f the stock solution so as to know hom much to dilute it for the various applica- ions. A Baume hydrometer should be purchased from the druggist and used for this esting. The following table quoted from Oregon Exp. Sta. Bul. 201 (14) tells how o make up the different strengths of spray depending upon the hydrometer or pecific gravity test of the concentrated stock solution.

DILUTION TABLE FOR LIQUID LIME-SULFUR

--Strength of stock solution--		To make 100 gallons of dilute spray use the number of gallons of concentrated stock lime-sulfur indicated in the columns below and add water to make 100 gallons.				
Degrees Baumé	Specific gravity	1 Dormant strength for scale clean-up (12-100)	2 Dormant strength for blister-mite & twig-miner (8-100)	3 Early spring spray ($3\frac{1}{4}$-100)	4 Mid-spring spray ($2\frac{1}{2}$-100)	5 Late spring spray (2-100)
		gal.	gal.	gal.	gal.	gal.
34°	1.304	11+	$7\frac{1}{2}$	3+	$2\frac{1}{4}$+	1-3/4+
32°	1.282	12	8	$3\frac{1}{4}$	$2\frac{1}{2}$	2
30°	1.260	12-3/4+	$8\frac{1}{2}$	$3\frac{1}{2}$	$2\frac{1}{2}$+	2+
28°	1.239	14 -	$9\frac{1}{4}$	3-3/4	2-3/4+	$2\frac{1}{4}$+
26°	1.218	15	10	4	3	$2\frac{1}{2}$
24°	1.198	$16\frac{1}{2}$-	11	$4\frac{1}{2}$-	$3\frac{1}{4}$+	2-3/4
22°	1.179	$18\frac{1}{4}$+	$12\frac{1}{4}$	4-3/4+	3-3/4-	3+
20°	1.160	20-3/4+	13-3/4	$5\frac{1}{2}$ -	$4\frac{1}{4}$-	$3\frac{1}{2}$

Note: Where the + sign is used, employ a little over the number of gallons indicated. Where the - sign appears use scant measure.

Commercial dry lime sulfur.

For several years it has been possible to buy on the market a preparation nown as "dry lime-sulfur". This product is made by the dehydration of concen- rated lime sulfur solution. It comes in the form of a powder which is readily issolved in water. It has the advantage of being less weighty and expensive to ransport and is easily prepared for use by dissolving the required number of ounds in the requisite amount of water. The preparation seems to lose slightly n efficiency during the process of manufacture so that it is usually necessary o use more of the dry lime sulfur in making up a tank of spray than the directions n the package recommend. If due allowance is made for this loss of strength, ery good results may be obtained with dry lime sulfur used as a substitute where rdinary lime-sulfur is usually used. Experiments have shown that 4 pounds of the ry lime sulfur preparation should be used for each gallon of liquid lime sulfur hat would be used for the same purpose. For example, in making up 100 gallons of rdinary lime sulfur spray of the 12 to 100 strength, 12 gallons of concentrated ime-sulfur is used for each 100 gallons of spray. If dry lime sulfur should be ubstituted for the concentrated solution it would take 48 pounds to make 100 allons of spray. This amount is more than is recommended by the label on the ackage but experience has shown that it is necessary to use these proportions to et the best results.

Substitutes for concentrated lime-sulfur.

The regular concentrated lime-sulfur is known to cause injury of various inds, especially in warm weather. Bordeaux mixture also causes injury under ertain conditions. To obviate this injury or for other reasons various sulfur ubstitutes are available. Among these substitutes for the standard lime-sulfur nd Bordeaux sprays are: Self-boiled lime sulfur, wettable sulfur, dry-mix sulfur ime and cold-mix lime and sulfur.

Self-boiled lime-sulfur.

For spraying peaches or other crops with sensitive foliage a specially pre- ared solution of limesulfur is recommended. In making self-boiled lime-sulfur o heat is used except that generated by the slaking lime. This results in only light chemical action between the sulfur and lime and makes a solution that is uch safer to use on tender foliage. The usual formula follows:

Sulfur	8 lbs.
Quicklime	8 lbs.
Water	50 gals.

Start the lime slaking by adding a small quantity of the water, about 2 allons. As the lime slakes mix the sulfur with it. Add water as needed. As oon as the boiling ceases add enough water to cool the mixture, strain and dilute o 50 gallons. This gives a spray that is largely a mechanical mixture of lime nd sulfur rather than a chemical combination as is true with the regular lime- ulfur described above.

Wettable sulfur (Sulfur paste)

Many substitutes for self-boiled lime-sulfur have been devised. They all consist of sulfur either alone or in mechanical mixture with lime or other substances. The active ingredient in all these substitutes is sulfur. It is not easy to wet sulfur in order to make it up in the form of a spray. To overcome this difficulty several brands of so-called "wettable sulfur" or "sulfur paste" have appeared on the market, as, for example, "Atomic sulfur" and "Colloidal sulfur". These pastes are readily diluted in water to make a sulfur spray. Sulfur sprays of this sort have about the same fungicidal value as sulfur applied in dust form and require a rather high temperature, 70 degrees Fahrenheit or above, for most effective action.

New Jersey dry-mix sulfur lime.

The New Jersey Experiment Station (16) has developed a substitute for self-boiled lime-sulfur which is claimed to eliminate some of the difficulties in the preparation of the latter. It consists of:

Sulfur	8 lbs.
Hydrated lime	4 lbs.
Calcium caseinate	8 ounces.

These ingredients are thoroughly mixed together while dry, then diluted with 50 gallons of water. Care must be taken to get the dry material wet thoroughly and evenly distributed throughout the diluted spray.

Oregon cold-mix lime and sulfur.

Robinson (14) of the Oregon Experiment Station has recently developed still another substitute for the self-boiled lime-sulfur spray, which he calls "cold-mix lime and sulfur". To make 50 gallons of this spray use:

Sulfur (Superfine flour)	8 lbs.
Hydrated lime	4 lbs.
Skim milk	2 quarts.

Mix the sulfur and hydrated lime together dry. Add 2 quarts of water to the 2 quarts of milk. Pour this onto the sulfur and lime and stir to form a smooth paste. Add more water if necessary. Add several gallons of water and pour through a strainer into the spray tank. When made up to fifty gallons the spray is ready to use.

Sulfur dust.

Since about 1912 there has arisen great interest in the possibilities of sulfur as a fungicide when used as a dust. During the years from 1912 up to the present time a vast amount of experimentation has been done to determine the value of sulfur dust as compared with the liquid spray, and many a lively discussion, not to say heated controversy, has been waged over the moot question of "Dusting versus spraying".

Properties of good dusting material.- The two prime qualifications of any fungicide which is to be applied as a dust are fineness and lightness. Formerly flowers of sulfur, a very fine sublimed sulfur was the best available but now it is possible to get finely ground sulfur which is much better than the flowers. In order to keep these fine forms from "caking" or forming lumps it is necessary to use some filler. It has been found that arsenate of lead dust forms an excellent filler, improving the dusting qualities of the sulfur, and at the same time makes a good combination insecticide. The usual proportions of sulfur and arsenate used in this combination dust is 90 parts of sulfur to 10 parts of lead arsenate, or 85 parts of sulfur and 15 parts of the arsenate. This combination dust is by far the most popular form of dusting sulfur although it may be applied occasionally as pure sulfur without any filler of any kind.

Dusting versus spraying.

During the last 10 to 15 years there has been among plant pathologists, entomologists and horticulturists a great interest in the feasibility of using dusts instead of liquid sprays.

In 1914 Blodgett (5) said: "The use of finely ground sulfur as the fungicide in a dust mixture has given very encouraging results (on apples) and warrants further trials on a more extensive scale."

In 1916 Stewart (6) in New York found that for leaf diseases in nursery stock "finely ground sulfur in the dust mixture proved as efficient a fungicide as lime-sulfur solution."

In 1918 Giddings (7) states that dusting did not prove satisfactory in West Virginia apple orchards, black rot, leaf spot and cedar rust not being appreciably controlled.

In 1919 Fromme and Ralston (8) in Virginia found that sulfur-arsenate dust controlled peach scab but was unsatisfactory for brown rot.

In Connecticut (1922) Britton (9) and others state that they compared dusting with spraying for apple pests and diseases and in nearly all cases obtained the best apples from sprayed plots. On peaches, however, the dusted plots gave slightly better fruit than the sprayed plots.

The above are only a few examples of experiments on dusting for disease ontrol. There is a large accumulation of literature on the subject and as shown bove there is lack of accord as to the value of dusts as compared with sprays. he facts are that there are advantages and disadvantages in both and that probably either can profitably be used to the exclusion of the other in all cases.

The matter can probably best be summarized by making a list of the advantages s well as the disadvantages of the dust fungicides.

Advantages.- (1) Requires less time for application. Some claim it takes only ne-fifth as much time as spraying. (2) Requires no water. This is quite an item hen water is scarce or not near at hand. (3) Labor cost of application is less. 4) Enables the grower to get a fungicide on in short order during critical periods r uncertain weather conditions.

Disadvantages.- (1) Material costs more per acre than sprays. (2) In many ases dusts are not as effective as sprays. (3) Dusts are more difficult to apply atisfactorily in windy weather.

3. Iron Sulfate.

While this chemical is not a good fungicide in itself, it is sometimes used .n connection with lime-sulfur for certain purposes. When added to lime sulfur it 'orms an iron-sulfide which is said to have good fungicidal qualities in some ;ases, notably when used against apple powdery mildew (11). It is also claimed ;hat it reduces the burning qualities of lime sulfur and makes it more adhesive. Some operators of spray outfits prefer to add a little iron sulfate to the lime-sulfur because of the black color it gives the spray. This enables the man with ;he nozzle to see how well he is covering the foliage and fruit.

A common formula is:

Iron sulfate ----------	2½ to 3 lbs.
Dilute lime-sulfur.---------	50 gals.

Dissolve the iron sulfate in a little dilute spray and add to the tank in the above proportions.

4. Potassium sulfide.

This is an old time remedy against certain fungus diseases such as powdery nildew of gooseberry. It is used as a spray made up after the following formulas:

Potassium sulphide ---------	3 oz.
Water ----------	10 gals.

5. Formaldehyde.

Formaldehyde is used chiefly as a disinfectant for seed, soil, containers, bins, etc.

It was formerly used quite extensively for treating seed wheat for bunt. For this purpose the formula in common use is:

Formaldehyde (37% to 40% strength) --------1 pt.
Water ----------40 gals.

At present formaldehyde is not used as extensively for treating seed wheat as formerly.

A so-called dry formaldehyde method of treating oats for smut is now used to some extent. This consists of sprinkling the oats with a solution of 1 part formaldehyde (37% to 40%) to 1 part water, applied with a small hand sprayer or atomizer.

Seed potatoes were formerly treated with formaldehyde, 1 pint to 30 gallons, for scab. It is not generally used for this purpose now, being superceded by corrosive sublimate.

For disinfecting containers, storage quarters, etc. a solution of 1 pint formaldehyde to 10 gallons of water is recommended.

As a disinfectant against certain soil organisms, formaldehyde may be used at a strength of 1 pint to 15 gallons of water, drenching the soil with 1 gallon of the solution to each cubic foot of soil. It is a good remedy for onion smut when applied to the soil in the drill rows at a strength of 1 gallon of formaldehyde to 50 gallons of water.

6. Mercuric Chloride (Corrosive sublimate).

Corrosive sublimate is the most effective disinfectant for seed potatoes against Rhizoctonia and scab. The usual formula is:

Mercuric Chloride ---------- 4 ounces.
Water ---------- 30 gallons.

Corrosive sublimate is also used at a strength of 1 to 500 as a disinfectant for tools when cutting out fireblight. It was formerly used on the wounds also in fighting this disease but proved to be ineffective on wounds and has been superceded by Cyanide of mercury for that purpose (See below).

7. Cyanide of Mercury.

Reimer (10) of the Southern Oregon Experiment Station in 1918 proved this chemical to be a much more effective disinfectant for wounds in cutting out fireblight of pears than any other substances heretofore used. He recommended a solution of 1 part mercuric cyanide to 500 parts of water.

8. Organic-mercury compounds.

During and since the great war a number of mercury compounds have been developed in Germany and placed on the market under such trade names as "Uspulun" and "Germisan". These are said to have proven very effective seed disinfectants

in extensive experiments carried out in Europe. More recently a similar substance has been produced in America and named "Semesan".

One of the advantages claimed for these new disinfectants is that they do not injure the seed in any way. It is even claimed that they increase the germinating powers of seeds in some cases. This is not true of formaldehyde and copper sulfate, the two fungicides most commonly used in the past. However, the new fungicides mentioned above are as yet more expensive than the older ones.

It remains to be seen whether these new compounds or others to be developed will ultimately replace those formerly used for seed treatment.

9. Creosote.

One of the greatest economic problems in connection with the use of lumber is the protection of timbers against decay organisms. In case of timbers which come in contact with the ground, such as railroad ties, telephone and telegraph poles, pilings and fence posts, enormous losses result from the untimely decay caused by fungi. It has been found that the usefulness of such wood products can be prolonged many years by impregnation with creosote. This is now done on a large scale under pressure in large tanks.

10. Sulfuric acid.

Some success has been achieved with sulfuric acid as a soil disinfectant for damping-off fungi in forest nursery seed beds. A solution of 1 ounce of acid to 1 gallon of water is said to give good control.

B. Heat as a fungicide.

Heat can be used as a fungicide in disinfecting seed and in soil sterilization.

As a seed disinfectant the use of heat has never become very wide spread or effective. Its chief use has been confined to the hot water treatment for loose smut of wheat and loose smut of barley. On account of the very particular pains which must be taken in order to be successful with this treatment it has never become very popular.

As a soil sterilizer heat can be successfully used, especially on a comparatively small scale, such as in greenhouses or outside seed beds. For this purpose both hot water and steam have been used.

Hot water.

Soil sterilization with hot water consists essentially in drenching the soil with water hot enough to kill harmful organisms.

Steam.

There are several methods of applying steam to the soil to kill parasites (1, 2, 3).

Steam-pan method.- For this purpose galvanized iron pans of convenient size and six to eight inches deep are used. These are inverted and the edges forced a few inches into the soil. A steam connection is provided at one end so that the pan can be connected with a boiler or other source of steam. Steam is thus forced into the soil, which should be loose, and the pressure maintained long enough to sterilize the soil. 80 to 150 pounds pressure for 30 to 60 minutes should do the work.

Perforated pipe method.- This outfit consists of a number of perforated pipes connected with a source of steam. These pipes are placed about 18 inches apart and 6 inches deep. After the pipes are imbedded cover the ground with canvas and turn on the steam.

Steam rake or harrow method.- This apparatus consists of a series of pipes with short sections coupled on like the teeth of a harrow. The "Teeth" are hollow but pointed and have small openings near the tips for the escape of the steam. After forcing the teeth into the ground it is covered with canvas or heavy cloth to keep in the heat and the steam is turned on.

Tile method.- This method (4) is a good one to install as a permanent system in the ground beds of a greenhouse. The system consists of laying tile lines about 20 inches apart and about a foot beneath the surface. These tile lines are connected with the steam heating plant so that steam can be turned into them whenever needed.

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CHAPTER VIII.

Plant Disease Control: Disease-free Seed and Nursery Stock.

Seeds and all other parts of plants used for propagation, such as nursery stock, bulbs, tubers and cuttings are capable of carrying diseases from the old crop to the new. The disease-producing organism may be carried (a) on the surface of the seed or other propagative part, or (b) embedded within the tissues thereof.

a. Surface-borne parasites.

Many diseases are disseminated on the surface of the host. There are several different forms in which various parasites may be carried in this way, namely: (a) As spores; e.g., Oat smut spores cling to the grain. (b) As sclerotia; e.g., Potato Rhizoctonia is perpetuated by the sclerotia which form on the surface of the tubers. (c) Bacteria; e.g., while seed-borne bacteria are probably more often carried within the tissues there are instances in which they are disseminated on the surface of the seed. The tomato bacterial spot (Bacterium vesicatorium Doidge) is said to be carried on the surface of tomato seed. (d) Vegetative mycelium; e.g., Powdery mildew can probably be disseminated in the mycelial stage on the surface of nursery stock.

b. Parasites embedded in host tissue.

Plant diseases are very extensively disseminated while embedded within the tissues of seeds, nursery stock, etc.

In Seeds.

Chen (17) has made an extensive review of the subject of internal parasites of agricultural seeds. Following is his classification of the forms in which pathogens are carried in the seed:

"The morphological structures or forms of the pathogens, in which they are carried within the seed, are highly important for the student of internal parasites of seeds to know. Based upon the previous findings the following categories have been made:

A. Sexual resting spores.

1. Oospores of the Phycomycetes--for example, Phytophthora phaseoli of lima beans (23).

2. Uredo and teleutospores of the Uredinales--for example, Puccinia graminis (13, 14). (61).

. Asexual bodies.

1. Vegetative forms of bacteria--for example, Pseudomonas stewartii of sweet corn wilt (85).

2. Vegetative mycelium of fungi-- The mycelium of a number of pathogenic fungi may invade the ovaries of the host without any marked or even evident injurious effect upon maturing seed. The intercellular mycelium in this condition suspends active growth during the dormant or resting period of the seed to resume active growth with the germination of the seed through the sprout of which it invades the growing plant. For example, Colletotrichum lindemuthianum of beans (90), Phoma lingam of cabbage (54), Botrytis authophila of red clover (15), Colletotrichum gossypii of cotton (2,3), Ustilago striaeformis of timothy (73), Ustilago tritici (19, 60), Ustilago nuda (19, 60), and Puccinia graminis of wheat (76,77).

. "Mycoplasma"--According to Eriksson, a fungus may exist in the seed in a "mycoplasma" form which serves as the means of transmission from crop to crop. For example, Puccinia graminis of wheat (30), Puccinia glumarum of wheat and barley (30), and Uromyces betae of beet (35).

. Unknown form (physiological virus)--for example, bean mosaic (78) and tomato mosaic (89)."

Chen has also given an historical review of the subject, a large part of hich is as quoted below:

"Introductory

"The first credible report of an internal seed infesting pathogen is that of ank (38, 39); who in 1883 found the anthracnose (Colletotrichum lindemuthianum) n beans in Germany. In 1885 Smith (83) reported the presence of telia of Puccinia aminis in the pericarp of oat kernels. Six years later, 1891, Halstead (47) iscovered the anthracnose in beans in America. In the following year, 1892, ach (5) stated that the bean blight (Pseudomonas phaseoli) may be carried within te seed. These earlier workers have marked the opening of the record of internal ed borne diseases. More detailed historical accounts regarding previous find- igs on the subject are to be presented under separate host plants in the following ction.

"Pathogens Found within the Seed of the Host Plant.

"Barley (Hordeum vulgare).

"The loose smut (Ustilago nuda) and rust (Puccinia glumarum) have been corded as internal seed borne diseases of barley. They are to be discussed ter under "Wheat".

"Beans (Phaseolus spp.).

"The anthracnose disease (Colletotrichum lindemuthianum) was demonstrated to e internally seed borne by Frank (38, 39, 52) of Germany in 1883. In America, 891, Halsted (47, 49) found the spores of the anthracnose in the cavity between he cotyledons, and believed that the disease can exist through the winter, or from he growing season to another in the mature beans. This was confirmed by Beach 5) in 1892. Whetzel (90) in his studies with bean disease in 1906 stated that the eed-coat of unripe beans is easily penetrated by the mycelium and the fungus is irectly established within.

"The bean blight (Pseudomonas phaseoli) was first noticed by Beach (5) in 892, and he believed that it is possibly carried within the seed. In the same ear Halsted (48) reported that the germs are carried over from season to season n the beans themselves. In 1906 Whetzel (90) noticed that the bacteria can gain ntrance into the seed and remain there dormant over the winter.

"Clinton (23) in 1905 presented evidence of the lima bean mildew (Phytophthora haseoli)' being carried within the seed in the form of mature oospores and ycelium.

"In 1917 Harter (51) reported that the podblight of lima beans (Diaporthe haseolorum) invades the seed and inhibits its germination. He also stated that he organism is easily isolated from the seed.

"Reddick and Stewart (78) in 1919 published an interesting account of the ransmission of the virus of bean mosaic in seed. They obtained over 50 per cent f mosaic plants from seeds which were diseased and sterilized externally in hloride of lime for four hours.....

"Cabbage (Brassica oleracea).

"The black-leg disease (Phoma lingam) of cabbage has been reported as being arried within the seed in the form of dormant mycelium by Henderson (54) in 1918. e was able to isolate the organism from the seeds after '(a) removed from the pod nder aseptic conditions, (b) exposures of 3,5,8 and 10 minutes, respectively, n a 1:1000 bichloride of mercury solution, and (c) immersion in a 1:200 solution f 40 per cent. formaldehyde for twenty-one minutes'. He also concluded that 'he fungus penetrates the seeds, causing them to shrivel and darken perceptibly.'

"Clover (Trifolium pratense).

"Bondarstev (15) in 1914 reported that the blossom mold disease of red lover (Botrytis anthophila) has been found within the seed coats in the form of ycelium. In 1916 Jaczewski (62) stated that the mycelium of the blossom mold ungus penetrates the clover seeds, thus transmitting the disease from year to ear and making the control difficult.

"Corn (Zea mays)

"Burrill and Barrett (20) in 1909 considered that the fusarium rot of corn s carried inside the grain. They detected the white mycelium of the fungus all ›ough the diseased grains. In 1916 Pammel, King and Seal (74) reported that the ›elium of Fusarium occurs abundantly in the embryo and endosperm of the corn in.

"Burrill and Barrett (20) in 1909 also reported that the mycelium of Diplodia e (Schw.) Lev., which causes ear rot of corn, penetrates the young tissue of the in.

"That Fusarium moniliforme (82) may be carried within the seed as the cause a serious root infection of corn plants in the field was reported by Valleau ') in 1920.

"Cotton (Gossypium hirsutum).

"That the anthracnose disease (Colletotrichum gossypii) is carried in the d was reported by Barre (2, 3,) in 1912. He stated that the fungus remains in interior of the seed as dormant mycelium and is able to live as long as 12 to months. In 1913 Gilbert (45) published an account of his experiment made in 05, in which he demonstrated that the fungus remained in the seeds and later led the seedlings.

"(Rolfs (79) in 1915 noted that cotton seeds may harbor the organism of the ular leaf spot (Bacterium malvacearum) in the inner tissues and when planted nsmit the disease to the young seedlings. However, in a recent study made by lwetter (37) in 1919, he concluded that the internal infection of the seed urs very rarely.

"Cucumber (Cucumis sativus)

"In 1915 Eriksson (36) in Sweden suggested that the diseases of cucumbers sed by Cladosporium cucumerinum, Cerospora melonis and Colletotrichum lagenarium internally carried through the seeds, involving the "mycoplasm" stage.

"Darnel (Lolium temulentum).

"Guerin (46) in 1899 noted the constant presence of a fungus in the form of elium in the interior of the seed. In 1902 Freeman (40), after performing a ies of experiments, ascertained the presence of the fungus in the embryo of the nel seed; and in 1914 he (41, 42) again noted internal infection by this fungus. name was given to the fungus, as its spores were not found.

"Evening Primrose (Oenothera sp.).

"Galippe (44) in his studies with the parasites of seeds reported in 1915 that 'B. anthracoides' is constantly present in the seeds of the evening primrose.

"Flax (Linum usitatissimum)

"The flax canker (Colletotrichum lini) was considered as a distinctly internal seed disease by Bolley (11) in 1910. Pethybridge and Lafferty (75) in 1918 reported that the fungus (Colletotrichum linicolum) causing the yellowing or damping-off of flax seedlings hibernates as mycelium in the epidermis of the seed coat. In the same year it was noted (1) in Ireland that a Colletotrichum causing a disease of flax seedlings hibernates in the skin of the seed and infects the plant while very young. The same fungus was probably referred to by different writers.

"Grasses (Gramineae)

"The occurrence of rust spores in the interior of seeds of grasses (Bromus mollis and Agropyron spp.) was noted by Beauverie (6) in 1913. He (7,8) again in 1914 reported that the fruiting bodies of the rust within the seed coats of grasses aid greatly the dissemination of the epidemic. See also "Wheat".....

"Oat (Avena sativa)

"In 1885 Smith (83) found telia of Puccinia graminis in the pericarp of oat grain and also thought that teliospores are carried inside the aleurone layer of the grain.

"Pea (Pisum sativum)

"That the blight of peas (Ascochyta pisi) is an internally carried disease was first considered by Halsted (50) in 1893. Later in 1895 Krueger (63) noted the fungous mycelium growing out from pea seeds which had been soaked in water for 48 to 72 hours. Van Hook (88) in 1906 stated that the fungus grows through the husk of infected pods into the seed and produces spores there.

"Dorothy Cayley (22) of England in her studies with a new bacterial disease of Pisum sativum reported in 1913 that the disease organism is transmitted in the interior of the seed.

Rice (Oryza sativa)

"In 1918 Nishikado and Myake (68) of Japan recorded the possibility of the brown spot disease (Helminthosporium oryzae) being carried within the rice grains.

Sweet Corn (Zea saccharata).

"That the grains of sweet corn contain the germs of the wilt disease (Pseudomonas stewartii) was first reported by Stewart (85) in 1898. Later, Cook (24) in 1918 stated that the bacterial wilt carried in the seed from year to year is the chief means of dissemination.

Timothy. (Phleum pratense).

"That the leaf smut (Ustilago striaeformis) may pass the winter in the embryo of the seed was demonstrated by Osner (73) in 1916. He noted that the smut enters the embryo of the seed, in the form of mycelium, through blossom inoculations.

Tomato (Lycopersicum esculentum)

"Westerdijk (89) in her report on experiments with the tomato mosaic in Holland in 1910 has claimed that the disease is hereditary through the seed.

Wheat (Triticum aestivum).

"In 1895 and 1896 Maddox (64, 65) of Tasmania noted the first evidence of internal seed infection in the loose smuts of wheat and barley (Ustilago tritici and Ustilago nuda, respectively). He stated that the ovaries of the wheat in the flowering stage can be artificially inoculated, and the grains developed from these infected ovaries produce smutted plants. Seven years later, 1903, Brefeld (18) observed the same occurrence. Hecke (53) in 1904 and Brefeld with his co-worker Falck (19) in 1905 have given a detailed account showing that the smut mycelium enters the ovary of the host plant and remains dormant in the mature grain. In 1907 Hori (60) reported the same result in his experiments in Japan. In America, Barrus (4) in 1908 and Freeman and Johnson (43) in 1909 published their conclusions in favor of previous investigators. Recently in 1918 Miura (67) of Japan has noted that the smut spores on the stigma of wheat and barley penetrate the tissue, and the fungus also was found in the embryo in the form of mycelium two or three days after the germination of its spores.

"That the rust of grains may be transmitted within the seed through the dormant mycelium was the belief of Smith (84) in 1886. However, Eriksson (29) in 1897 advanced the mycoplasm theory for the transmission of the rust of wheat

and barley (Puccinia glumarum). Zukal (92) in 1899 supported the dormant mycelium theory of Smith, and concluded that the mycelium lived over in the seed and grew into the embryo through the scutellum and developed with the plant. In the same year, Masse (66) developed the seed-borne spore theory. Later in 1914 Beauverie (7) found the spores of Puccinia glumarum within the seed coat of barley.

"A conclusion was drawn by Eriksson (30) in 1898 that the common rust of wheat (Puccinia graminis) is inherited from the mother plant in the seed grain and lives there in a latent form which he called "mycoplasma." He (31) again in 1902 claimed that cereal rusts cannot be propagated either by an intercellular mycelium, or by groups of spores on the surface or in the interior of the grain. He further claimed that the uredo and teleutospores are not abundant enough to cause an habitual infection. However, in 1905 and 1906 Bolley and Pritchard (13,14) found both uredospores and teleutospores of the rust beneath the bran layer of the grain, and believed that the disease might be transmitted in this manner. Pritchard (76,77) in 1911 presented evidence in that the rust may be transmitted as dormant mycelium in the seed. In 1914 Eriksson (34), referring to an article by Beauverie (6) and the report by Pritchard (77) stated that he had reported the occurrence of rust spores in seed of cereals in 1896, but that he considered it abnormal and not of practical importance in the propagation of the rusts.

"Hungerford (61) in 1920, after a careful and extensive experiment, reported that the stem rust is not transmitted from one wheat crop to the next through the infected seed grain although the uredinia and telia have been found embedded in the pericarp of wheat kernels.

"The wheat scab (Fusarium roseum) was proved by Selby and Manns (81) in 1909 to be carried within the wheat kernel as an internal parasite.

"In a study of the fungus flora of the straw and seed of wheat in 1913, Bolley (12) made the following statement: 'They are Alternaria, Macrosporium, Helminthosporium, Acrothecium, Colletotrichum, Fusarium and Cephalothecium. Each of these can be obtained from the seed coats and interior of the grains from this section and from wheat samples from almost any wheat growing region in the world.'

"In 1915 O'Gara (72) reported a new disease of germinating wheat (Podosporiella verticillata) destroying the contents of wheat kernels at or near the time of germination. He also found the fungus producing no growth external to the wheat kernel, being wholly within the epidermal covering."

In other propagative parts.

Many diseases can be carried in nursery stock. The bacterial diseases, fire-blight and crown-gall are undoubtedly disseminated in this manner, by means of living bacteria hidden within the host tissues. Fungous diseases such as Black-rot canker, Blotch, European canker and Northwestern anthracuose can be carried in apple nursery stock either as hidden mycelium or as pycnidia or other fruiting forms embedded in the bark. The Armillaria root rot fungus can be carried as vegetative mycelium in the roots of nursery stock.

Seed potato tubers are known to carry several diseases within the tissues. Late blight (Phytophthora infestans) is carried as vegetative mycelium within the tubers. Blackleg (Bacillus phytophthorus), a bacterial disease is carried either within or on potato tubers. Fusarium and Verticillium wilt organisms hibernate within potato tubers. Nematodes are disseminated in tulip bulbs.

Methods of obtaining clean seed and nursery stock.

There are several different methods of obtaining clean seed, any one or all of which may be of use in dealing with any particular disease, depending, of course, upon the nature of the disease, the host and other conditions. These various means are: seed disinfection, selection, roguing, securing seed from a disease-free locality, and the use of a special seed plot.

Seed disinfection.

Whenever a disease is borne entirely upon the surface of the seed or other propagative part, there is always the possibility of getting rid of it by one of the various seed treatments, either by use of chemicals or heat. Examples of this are the familiar treatments for grain smuts by formalin, copper sulfate, copper carbonate or hot water, and the corrosive sublimate treatment for seed potatoes.

Selection.

It is many times possible, if feasible, to sort seed, selecting only disease-free seed for use. It is doubtful if this could be 100% efficient in most cases because of the probability of overlooking slightly diseased specimens. For example one might select seed potatoes which appeared to be free from Rhizoctonia or scab but it would be impossible to be sure that all disease had been eliminated so it would still be necessary to resort to seed disinfection in cases of this kind. However, in case of internal parasites where treatment with chemicals can not be successfully done, it is still necessary to practice selection or some of the other methods mentioned below.

Seed from a disease-free locality.

It is many times possible to find a disease-free field in ones own community or to go to another locality which is free from disease when securing seed for a new crop. As a rule this is a much better practice than to attempt to select sound seed from a diseased lot.

Special seed plot.

In case of some diseases it is advisable to maintain a special, isolated plot for growing seed where a special effort is made to keep out diseases. The seed plot should be as far as possible from another field of the same crop and should be changed or rotated from year to year, especially if any disease should show up in the plot.

Roguing.

With many crops, as potatoes, it is possible to detect many of the diseases during the growing season. The diseased plants should be rogued or pulled out and destroyed as soon as detected. This practice is especially recommended in the special seed plot and is usually required where seed certification is practiced.

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CHAPTER IX.

Plant Disease Control: Quarantine and Inspection.

The fact that any particular plant disease or pest is usually not cosmopolitan in the beginning but has a more or less limited range in certain countries or regions, and that sooner or later, due to the activities of man in transporting plants or plant products from one country to another, this disease is apt to be carried to countries or regions where it hitherto has not existed, has led governments to set up quarantine regulations to prevent such spread.

However any quarantine measures attempting to regulate the spread of plant diseases either between countries or between parts of the same country must be based upon sound biological principles as regards life habits of the disease organism,its hosts, etc. Orton and Beattie (3) discuss this whole problem so fully and clearly that we quote their article in almost its entirety:

"The Biological Basis of Foreign Plant Quarantine.

"Plant diseases and insect pests are often limiting factors in crop production and their prevention or control is one of the major problems of agriculture.

"In all developed countries the introduction and spread of such pests in the past has caused such heavy losses, even to the point of restriction or abandonment of important crop industries, and now imposes such a heavy annual tax for sprays, seed treatments, cultural control and the substitution of resistant varieties of cultivated plants that the people have invoked governmental aid to apply official regulatory measures which will protect them from additional burdens of this character in the future.

"The efforts that are being made along this line may be grouped under four heads, according to the prevalence status of the pests involved:

1. State Inspection and Certification of Plants and Plant Products.- All progressive countries maintain inspection services for the general control of insects and plant diseases, including those already common, widespread or endemic, through supervision of commerce in nursery stock, seeds and plant products.

2. Eradication.- To wipe out newly introduced parasites presenting an unusual menace to our crop industries. Two outstanding illustrations are the fight waged against citrus canker in Florida and that against the pink bollworm of cotton in Louisiana and Texas. The eradication method has also been applied successfully to outlying "long jump" infestations of gypsy moth and other insects. As a rule, it is extraordinarily difficult to eradicate an insect or disease that has gained a firm foothold in a region favorable for its maintenance.

3. Domestic Quarantines.- Restriction of new introductions by local or domestic quarantines drawn around an area where a new pest from a foreign country has

become established. Examples are the quarantine against the gypsy and browntail moth in New England, the Japanese beetle in New Jersey and Pennsylvania, and potato wart in three states.

"In the same category may be placed the efforts made by various states to keep out pests established in other, often distant states. Arizona regulates against cotton pests from the East, alfalfa weevil from the North, citrus pests from the South, and grape phylloxera from the West. In such cases a barrier has been erected around the pest-free area rather than around the infested area.

"These local or domestic quarantines are temporary expedients, whereby the spread of a pest is slowed up or held back at heavy cost and much inconvenience, but domestic dispersal is almost unrestrainable and, sooner or later, the point is reached where the newly established pest acquires the status of other widely distributed parasites, to which we have to adjust ourselves forever.

4. Foreign Quarantines.- These seek to exclude the plant pests of other countries on the principle that frontier boundaries are the most effective fighting lines. It is primarily with this problem that we are to deal in this paper.

"We stand in danger of subjecting ourselves to ineffective and hampering regulations without adequate gain unless the quarantine procedure is based upon a firm scientific foundation of sound biological principles derived from properly coordinated facts relating to the nature of the parasites to be dealt with, their country of origin and geographic distribution, their host relations, and the native home of the host, prevalence, climatic relations, manner of spread, and other factors. More studies of this character need to be made, but enough is known to enable some general principles to be established.

"Foreign Quarantine Problems Distinct.

"It is our purpose to emphasize that the application of biological principles to plant quarantines must lead to a primary distinction between the problem of control of spread within a given area, which has been termed 'continuous spread', and the long distance transfer that has been termed 'discontinuous spread' by Butler (1) in his excellent monograph on this subject.

"It was pointed out in 1914 (2) that we have to deal with an intercontinental problem and that to safeguard the exchange of plants and their products between countries situated in different continents more stringent precautions might become necessary.

"That in establishing plant quarantine policies the problems of restricting parasites from foreign lands must be grouped separately from the problems of preventing or delaying dispersal of pests already locally established may appear self-evident to some, but that this important point is not yet properly acknowledged is shown by the report of the last International Phytopathological Convention held in Rome in 1914, which makes no distinction between contiguous and non-contiguous countries, with respect to the methods to be adopted to prevent the spread of plant parasites. The representations made by European delegations to

the Federal Horticultural Board during the past year have likewise ignored this basic principle, and have included proposals for intercontinental exchange of plants that we must regard as extremely unscientific and dangerous.

"The Basal Principle of Biological Equilibrium.

"The plant parasites of one continent or natural plant zone are likely to be more virulent and destructive when introduced into another continent or plant zone than they are at home, where they are in equilibrium with their hosts and associates. This principle of biological equilibrium in Nature is best understood by considering from the viewpoint of evolution the results of the complex interactions of organisms, the struggle for existence, the influence of animals on plants, of plants on animals, and the disturbing effect of man, who seeks to exterminate some animals and plants and increases the number of other organic elements in the equation, even bringing in foreign organisms to participate in the mixup.

"In the course of evolution many marvelous adaptations to environment arise and many complex interrelations develop. Organisms are sheltered by some of their associates and preyed upon by others. They become dependent upon certain kinds of food, and increase or diminish in numbers with the abundance of this food.

"The type of relations that concerns us is parasitism, wherein one organism lives upon and at the expense of another. A classification of parasites on the basis of their adaptation to their hosts reveals the course of evolution, which has progressed from saprophytism, through wound parasites and weakling parasites, toward a stage of closer adaptation between host and parasite till symbiosis is reached, a relation where the parasite does little or no injury or even stimulates the host to larger growth till the reproduction and dissemination of the parasite is assured.

"There is a tendency for the fungus or bacterium to reduce its toxin formation, and on the part of the host to develop a degree of immunity, so that a balance is established between the two, with a lessened injury to the host and a more highly perfected mechanism of dispersal for the parasite. With insects, the balance is established more often through the influence of parasites, predatory insects, and birds.

"This equilibrium is dynamic, not static, ever changing, but tending to preserve the status quo, and in the establishment of equilibrium the time element is important. While the restoration is slowly taking place in a new country much economic damage often occurs.

"So it comes that the natural parasites of a region are not highly destructive to the plants of that region, as a general rule, but when one of these parasites is transferred to a different plant zone, it may come into contact with a new set of organisms and find new hosts that are not resistant.

"In considering the problems that arise when a new plant disease or insect is discovered to have been introduced, or in estimating the risk presented by a foreign parasite, it is well to begin by ascertaining:

1. The country where the parasite is endemic.

2. Its native or original host.

3. The geographic distribution of this host.

4. Its relationship to other economic plants in our country.

5. If the host is cultivated here, to what extent and for how long it has been subjected to plant breeding that may have resulted in the production of distinctively American strains whose resistance to the parasite is unknown.

"Various types of disturbance of biological equilibrium by the transfer of parasites from one plant zone to another occur and may be illustrated by notable examples.

"I. A parasite introduced from one continental zone to another finds susceptible hosts. A conspicuous instance where aforeign fungus has found an American host more susceptible than its original host is the chestnut bark disease, Endothia parasitica, which occurs in Asia on Castanea mollissima as a relatively minor trouble, but introduced into the United States by accident, has attacked our Castenea dentata most virulently and will practically destroy all the chestnut forests of the country before it stops. In America this Asiatic parasite has found the European chestnut, Castanea vesca, as easy prey as the American and if introduced into Europe it may yet repeat there the devastation we have witnessed here. Europe has already suffered heavily from introductions of this type. The wine grape, Vitis vinifera, has been scourged in succession by the phylloxera, the downy mildew, Plasmopara viticola, and the black rot, Guignardia bidwellii, to all of which American species of Vitis are resistant.

"European gooseberries are found to be susceptible to the American mildew, which is becoming widespread in Europe. We have long known that the European varieties were relative failures in the United States on account of this mildew, to which American species are resistant.

"The white pine blister rust, Cronartium ribicola, a native of Europe on Pinus cembra and other species is very destructive to Pinus strobus in the United States, and another American species, Pinus monticola, is several times as susceptible as P. strobus. This had been forecasted prior to the actual introduction from the injury done to American white pines when planted in Europe.

"The hollyhock, a native of China, met the rust, a South American fungus, in Europe and its culture wasnearly stopped. The disease later spread to North America and repeated its destruction here.....

"II. A plant, carried from one continental zone to another, is attacked by new parasites. The culture of maize in Java and the Philippines is well nigh impossible because of the corn mildews, Sclerospora spontanea, S. maydis, S. sacchari, and S. Philippinensis, which are oriental species, the latter being native on Saccharum spontaneum and Miscanthus japonicus.

"When the common potato in its spread from South America reached the Rocky Mountains of the north, it was attacked by the Colorado beetle, Doryphora decemlineata, which found the newcomer more palatable than the Solanums on which it had been accustomed to feed.....

"As already mentioned, the European gooseberries brought to America were attacked by the American mildew and the attempts to establish the culture of European grapes in eastern North America were always failures on account of phylloxera, black rot, and mildew.

"III. A cultivated plant, transferred from one continent to another without its parasites, is later followed by them. In the interval, new varieties have arisen which do not possess the high resistance the species originally had. Our American agriculture is based so largely on introduced crops that we have had numerous cases of this type in the past and there is ground for grave apprehension that still others may be brought in. The asparagus rust affords a significant illustration of this phase of this biological principle. Asparagus and its rust are both native Europeans and the disease is not highly injurious on that continent, but the crop came to the United States without the disease and from its earliest culture until about 1896 was free from rust. During this period American varieties were bred and formed the basis of our industry when the rust finally invaded the United States. It soon transpired that the Americans strains of asparagus which had been developed in the absence of the rust and never before had been in contact with the disease were very susceptible, and they were soon wiped out. European strains were imported and resistant types selected from them. These have now replaced the old susceptible kinds, and an interesting thing has happened. Asparagus rust has dwindled and in places almost disappeared; in other words, we have restored the natural equilibrium such as exists in Europe.

"IV. Domestic parasites are sometimes limited in their natural geographic distribution by climatic factors. The black rot of grape, which requires high temperatures for infections, is most at home in the central eastern states. A New England grape from Vitis labrusca the Concord, is more susceptible in that region than are varieties derived from Vitis rotundifolia. Pecan scab, Fusicladium effusum is most destructive to varieties from the southwest, Texas for instance, planted in the more humid region of the Atlantic Seaboard.

"The vast areas planted to one crop in the United States make for a disturbed equilibrium and afford favorable conditions for the rapid spread of parasites.

"The transfer of plant parasites from continent to continent was extremely slow in the early days when the means of communication were scanty and the voyages long, but notable instances have multiplied in proportion as the volume of traffic increased. World trade is certain to be on a still larger scale in the future, with proportional risk of spreading pests unless scientific control measures are rigidly enforced.

"Natural Barriers against Plant Pests.

"What are the plant zones within which organic life is in a state of equilibrium? Clearly they are in the main continental. The extent to which mountains and deserts restrict the spread of parasites has never been adequately studied but such cases are known. Here is a field to be highly commended to investigators.

"It will be clear that the plant relations of two contiguous countries without a natural barrier are different from those of two countries separated by an ocean barrier. In the first instance the endemic parasites are the same and respect no political boundaries. The plants and parasites of the United States have reached their ultimate distribution except as new introductions are still spreading.....

"Since plant parasites are in dynamic equilibrium with their natural hosts, with a tendency toward reduced injury, it follows that it is now impossible and that it never will be possible to foretell from the behavior of the disease or insect in its native home what it may do when transferred to another continent. Experience has shown that in many cases we may expect it to go over to a near related host and attack this plant with great virulence.

"It is important to study in Europe and Asia the diseases of American plants that have been introduced there. For example, we knew in advance that the European blister rust was especially destructive to American white pine, because that tree had been much planted in Europe and had failed there because of the rust.

"The effect of the canker due to Phomopsis pseudotsugae recently reported from Scotland upon the American species of Pseudotsuga, Larix, Tsuga, and Abies, now growing there deserves careful study in the light of the importance of our western Douglas fir forests.

"Most of our cultivated plants are native to other continents, but crop plants are subject to rapid change by breeding and the resistant character previously attained abroad may be dropped or diminished unawares. Since our present day varieties are of American origin, bred for adaptation to our climate and soil, it is to be expected that as additional parasites accidentally become established they will be more destructive to our American bred varieties than they are to the parent species in the original habitat. The need for strict exclusion is therefore so much the greater.

"Crop Introduction.

"To promote the agriculture and horticulture of a new country, it is desirable to introduce the crop plants of other lands. It is possible, and highly desirable, to accomplish this without bringing along their parasites. For example, we have the Australian eucalyptus on the Pacific Coast with very few pests, whereas in its native country it has a good many parasites. This is probably due to the fact that our introductions have been by seed rather than by plants. Unfortunately, this freedom from pests can be said of few of our great staple crops. Many diseases of wheat, potatoes, apples, peaches, etc. trace back to the original habitat of these

crops. What losses beyond the possibility of estimation might have been saved if national barriers against plant pests had been erected at the start. However, by no means all of the crop pests of other lands have been imported and we have still many new plants to bring in. It is to be hoped their enemies may be left behind.

"At this point we may expect to hear from the man who proposes that it would be better to let all the foreign parasites in and strike a balance with them, developing control method once for all.

"Unthinkable! Count the cost of a few more scourges like the chestnut bark disease. Could our corn growers combat the Philippine downy mildew? In his description of the ravages of this disease in the Philippines, Weston describes fields where practically every plant was destroyed and he believes that climatic conditions in our corn belt would favor the mildew. It is difficult enough to establish the culture of a new corn in the absence of its serious pests. It would become impossible if all the enemies were brought in.

"Moreover, a biological equilibrium would never get established, for the succession of possible pests from all the ends of the earth is endless. There would always be more to come. We would not learn to cope with one enemy before another would be upon us.....

"What are the Factors Governing the Spread of Plant Parasites?

"Theorists might stress wind carriage. Volcanic dust has been borne thousands of miles through the air. Why not fungus spores?

"But no case of long distance transfer of plant disease by wind has been demonstrated, and the facts of geographic distribution show that diseases frequently have failed to spread even short distances until carried by man. There is a place in the District of Columbia where for twenty years apples and red cedars have been growing in close proximity without a trace of cedar rust, though ten miles away this fungus is a scourge to both hosts. Butler, after an extensive review of the evidence, concludes, that 'infection by spores carried through the air from remote centers is not a contingency which needs to be seriously taken into account'.

"Ballast brought to our shores in the holds of vessels from foreign ports is a bugaboo to the theorists, but no case of disease importation has been traced definitely to it. The practice should be regulated and ballast of live or agricultural soil prohibited. Earth balls on the roots of imported plants stand in a very different relation and are much more dangerous, as they are the resort of many insects and may contain harmful fungi or nematodes.

"Spores have been found on birds, and birds fly long distances. Clearly they might spread infection, but the facts of distribution already referred to and studied, of the spread of great plant epidemics, indicate that spread is mainly by continuous dispersal, or in long jumps through human agencies.

"Plant Diseases Spread by Man.

"The most frequent agent in plant pest dissemination is man, and the outstanding and altogether most important medium of transfer is living plants or parts of plants for propagation. Trees, roots, bulbs, and seeds, taken in a living condition from their place of origin, with parasites attached, are carried to a new location, set out, and brought into growth. The careful moist packing and cultural precautions taken to preserve their vitality likewise insure the perpetuation of the parasite.

"Insufficient consideration has been given to dispersal on seed through external or internal infection, which has carried many plant parasites over the world. War needs brought a shipload of castor beans from India to Florida, and with it a Botrytis blight that made the culture of this crop impossible. Investigation proved that the parasite was seed-borne.

"Practically all of the pest transfers of which we have accurate record have taken place in this way. In the nursery a large number of related species of plants are brought together in such a way as to favor continuous spread. If these plants become infected the discontinuous spread of the disease may occur when the nursery stock is shipped to distant parts of the world. Thus in the majority of cases the nursery is the principal center of distribution.

"We must lay it down as an unchangeable law of nature that intercontinental trade in plant propagating material is fundamentally dangerous, and to be held within the narrowest limits compatible with economic need.

"In human diseases the same principles apply. The living carrier is a greater risk than air-borne infection. The practices of the most progressive public health authorities show an increasing recognition of this principle.

"Inspection inadequate.

"Experience has shown that by an inspection of plants in nurseries, or better in the packing house, a worth while safe-guard is provided for shipments to contiguous states in the same biological zones, since the number of parasites is greatly lessened, but the most rigid inspection can not detect all the insects, as shown by the frequent findings of brown-tail moth nests in certified nursery stock upon its arrival in America from North Europe. How much less likely are the inspectors to discover the presence of fungous and bacterial diseases, due to organisms of minute size and often embedded in the tissue of the host plant, as in the case of white pine blister rust, where an internal infection of seedlings shipped to America from Europe has been detected two or three years later.

"There are three biological factors which operate to make inspection inadequate for intercontinental shipments.

1. Human powers of observation are not keen enough to detect 100 per cent of visible shipments.

2. Some parasites are internal, without outward manifestation.

3. Organisms common and of minor consequence in one biological zone may become destructive parasites in another biological zone.

"The tendency of inspection officials has been to overlook 'common species of long standing dispersion', to quote the language of the Rome Convention, which in addition omits from consideration 'enemies of plants whose ordinary supports do not exist in the importing countries', and those which do not present:

1. An epidemic character.

2. A destructive or at least very harmful action on cultivated plants.

3. An easy propagation by living plants or parts of living plants.

"These considerations are logical only when applied to contiguous countries. To other continents the only effective protection is the nearest approach to absolute exclusion of living plants that economic needs permit. Importations for propagation of new or rare varieties should be under governmental supervision, and if the origin is in unsurveyed countries they should be grown for a period in a quarantine or detention station, and in any case should be given the most effective treatment possible.

"Treatment Methods Inadequate.

"Fumigation of plants is a safeguard, but not a complete protection.....

"No method has been devised to disinfect seeds or plants that can be depended upon to reach all fungi and bacteria present, though such treatments are of value in particular cases.

"What then of Plant Products for Food or Manufacture?

"This is an important question, because such commodities form a large part of our trade, both export, import, and domestic and extensive restriction might prove more harmful than helpful.

"Here again, proof is lacking, except in a few instances, that plant pests are actually disseminated, and these cases are mostly those where the commercial product is a seed, tuber, or part capable of propagation. Cotton seeds are dangerous carriers of pink bollworm. Potatoes introduce disease to the extent that table stock is used for planting. Tuber parasites are transported with particular ease. Apple fruit has not spread San Jose scale. This scale has not become established in northern Europe although often present on fruit imported from Australia. Pear fruit does not expose the importing country to a risk of pear blight. Fruit flies, however, are carried in commercial fruit and may escape

therefrom and are therefore subject to discontinuous spread. Each case is a problem for research and separate consideration.

"It highly behooves those interested in building up an intercontinental trade in plant products to take measures to provide a safe foundation for such enterprises, to insure that the importation of a fruit or vegetable or other plant product will not later become a means of exposing North American crops to injury from a new disease or insect.

"This foresight can be exercised through scientific research in the country of production, in tropical America, for example, to keep out pests or to keep them down, or to develop methods of culture and packing that will make it impossible for pests to be spread.

"Summary

"Plant quarantine policies and methods must be founded on nature's laws governing the dispersal of parasites.

"The problems of discontinuous spread between countries separated by ocean or other natural barriers are therefore different from those of continuous spread in adjacent countries.

"The pests of other continents are fundamentally the most dangerous. Seldom can they be known in advance or completely eliminated by inspection. Consequently intercontinental trade in living plants will always be attended by such grave risks that it should be held within the narrowest limits compatible with economic needs."- Orton, W. A. and R. Kent-Beattie. Phytopathology. July, 1923. The Biological basis of foreign plant quarantines.

Quarantine Laws.

As a sample of the types of laws that have been enacted to meet the need for exclusion of plant diseases from uninfected countries or regions, the following sections are quoted from the Federal Quarantine Act of 1912 and subsequent amendments.

Preventing introduction of new plant disease or injurious insect; excluding classes of nursery stock or plants.

"Whenever, in order to prevent the introduction into the United States of any tree, plant, or fruit disease or of any injurious insect, new to or not theretofore widely prevalent or distributed within and throughout the United States, the Secretary of Agriculture shall determine that it is necessary to forbid the importation into the United States of any class of nursery stock or of any other class of plants, fruits, vegetables, roots, bulbs, seeds, or other plant products from a

country or locality where such disease or insect infestation exists, he shall promulgate such determination, specifying the country and locality and the class of nursery stock or other class of plants, fruits, vegetables, roots, bulbs, seeds, or other plant products which, in his opinion, should be excluded. Following the promulgation of such determination by the Secretary of Agriculture, and until the withdrawal of the said promulgation by him, the importation of the class of nursery stock or of other class of plants, fruits, vegetables, roots, bulbs, seeds, or other plant products specified in the said promulgation from the country and locality therein named, regardless of the use for which the same is intended, is hereby prohibited; and until the withdrawal of the said promulgation by the said Secretary of Agriculture, and notwithstanding that such class of nursery stock, or other class of plants, fruits, vegetables, roots, bulbs, seeds, or other plant products be accompanied by a certificate of inspection from the country of importation, no person shall import or offer for entry into the United States from any country or locality specified in such promulgation, any of the class of nursery stock or other class of plants, fruits, vegetables, roots, bulbs, seeds, or other plant products named therein, regardless of the use for which the same is intended: Provided, That before the Secretary of Agriculture shall promulgate his determination that it is necessary to forbid the importation into the United States of the articles named in this section he shall, after due notice to the interested parties, give a public hearing, under such rules and regulations as he shall prescribe, at which hearing any interested party may appear and be heard, either in person or by attorney....." (Act. Aug. 20, 1912.)

Importation for scientific purposes.

"Hereafter any class of nursery stock or of any other class of plants, fruits, vegetables, roots, bulbs, seeds, or other plant products of which the importation may be forbidden from any country or locality under provisions of section seven of the plant quarantine act approved August twentieth, nineteen hundred and twelve..., may be imported for experimental or scientific purposes by the Department of Agriculture upon such conditions and under such regulations as the said Secretary of Agriculture may prescribe." (Act March 4, 1913).

Interstate quarantine against plant disease or insect infestation; transportation from quarantined places forbidden; rules and regulations for inspection and shipment; hearings.

Acts of Aug. 20, 1912 and Mar. 4, 1917 provide that, whenever a plant disease or pest is introduced into or exists in a limited area of the United States, the Secretary of Agriculture is authorized and directed to promulgate such quarantine and inspection regulations as seem necessary to prevent the spread of such plant diseases or pests into uninfested territory.

(Authority for the above laws--Barnes' Federal Code, 1919).

State Quarantine Laws.

The states have also passed quarantine and inspection laws, modeled more or less after the Federal Acts. Below are quoted sections from the Oregon law on this subject:

"Proclamation of Governor Prohibiting Importation of Nursery stock Etc.

"That whenever, in order to prevent the introduction into the State of Oregon of any tree, plant or fruit disease, or of any injurious insect or animal not theretofore widely prevalent or distributed within and throughout the State of Oregon, the commissioner at large of the State Board of Horticulture shall determine that it is necessary to forbid the importation of any class of nursery stock or of any other class of plants, fruits, vegetables, roots, bulbs, seeds or other plant products or of any articles which are naturally, or liable to be, the hosts of such injurious diseases, insects or animals, from country or locality where such disease or insect or animal infestation exists, he shall promulgate such determination, specifying the country and locality and the class of nursery stock or other article which in his judgment should be excluded. Following the promulgation of such determination by the commissioner at large of the State Board of Horticulture, and until the withdrawal of said promulgation by him, the importation into the State of Oregon of the article or articles specified in the said promulgation from any country or locality specified in the said promulgation is hereby prohibited; provided, that before such promulgation becomes effective the governor of the State of Oregon shall approve such promulgation in writing thereon, and such promulgation so approved shall have been published in three newspapers designated by the governor in writing. Whenever the commissioner at large of the State Board of Horticulture deems it for the best interest of the State of Oregon to withdraw such promulgation, he can do so with the written approval of the governor of Oregon, by publishing a notice of such withdrawal in three newspapers to be designated by the governor. Proofs of publication of such promulgations and withdrawals of promulgations shall be filed in the office of the secretary of state. (L. 1913, Chap. 246. Sec. 1)."

"Inspection of Nursery Stock, Etc., Brought into State.

"Any person, persons, or firm or corporation who shall bring or cause to be brought into the State of Oregon, any nursery stock, trees, shrubs, plants, vines, cuttings, grafts, scions, buds, fruit pits or fruits or vegetables, shall immediately after the arrival thereof notify the state inspector, if he be in the county in which such articles are received, of their arrival, and hold the same without unnecessarily moving the same or placing such articles where they may be harmful, for the immediate inspection of said state inspector or county inspector or other person authorized to make such inspection. If there is no state inspector in the county in which such article is received, it shall then be the duty of such person, firm or corporation tonnotify the county inspector of the county in which the article is received. If there is neither state inspector nor county inspector in the county in which such article is received then it shall be the duty of the person, firm or corporation, to notify the commissioner of the State Board of Horticulture for the district which includes said county who shall make immediate

arrangement for the inspection of such article or articles. The commissioners of the State Board of Horticulture and their deputies, the secretary of the State Board of Horticulture, the state inspector, and the county inspectors and their deputies are hereby authorized and empowered to enter at any time into any car, warehouse, depot or upon any ship within the boundaries of the State of Oregon, whether in the stream or at the dock, wharf, mole or any other place where such nursery stock or fruit, or vegetables, or seed, or other such articles are received, or in which any of such articles are imported into the state, for the purpose of making the investigation or examination to ascertain whether such articles are infested with any injurious insects or their eggs, larvae, or pupae, or other animal or plant disease.

"If, after such examination or inspection, any of said articles are found so infected or infested, then it shall be the duty of the owner, owners, or persons, firm or firms, or corporation having charge or possession thereof to so disinfect at his or their expense such portion or portions of the ship, dock, wharf, mole or car or warehouse or depot where such articles may have been located in such a manner as to destroy all infection or infestation present, and all articles apt to be so infested or infected shall be held until the said articles have been thoroughly disinfected and all injurious insects, or their eggs, larvae or pupae or other animal or plant diseases have been eradicated and destroyed; provided, however, that all articles of nursery stock, trees, shrubs, plants, vines, cuttings grafts, scions, buds, fruit pits, fruits, vegetables or seed which are infested or infected with injurious insects or their eggs, larvae or pupae, or other animals, or with injurious plant disease liable to cause damage in this state, shall be destroyed or reshipped out of the state as hereinafter provided.- (L. 1913, Chap. 246, Sec. 41)."- Rept. Ore. Board of Hort. 1923. pp. 42-44.

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(5) Stewart, V. B. Exclusion legislation and fruit tree production. Phytopath. 8: 360. July, 1918.

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CHAPTER X.

Plant disease control: "Sick soil".

All crops grow in the soil therefore the condition of the soil has a great deal to do with determining whether or not a crop can be profitably grown. When a soil is in normal condition for the production of a fine crop it may be called a "healthy" soil. The term "sick soil" has come into common use to designate a condition wherein a soil will no longer grow a given crop profitably. Taubenhaus (5) has discussed this problem somewhat in detail, dealing first with those conditions which make for a normal healthy soil of good productivity, and then taking up the causes of "sick soil". The latter, he says, may be due to either non-parasitic causes or may be caused by harmful parasites in the soil. Parts of his discussion are quoted below:

I. "The Normal Soil and its Requirements...

"It is to be regretted that laymen often regard the soil as merely a conglomeration of inert particles of dead rock. If this were true, plant life would be an impossibility. It is because soils are teeming with various forms of organisms beneficial to them that plant life is made possible therein.....

"Indeed we may judge soil by the kind of flora which predominates there, and call it fertile and healthy when this germ life helps to make it a favorable medium for the plants. On the contrary we call it sick or poor when it teems with bacteria and fungi which act as parasites on plants, or when the beneficial ones are absent or perform their duties imperfectly.....

"Relationship of Bacteria to the Function of a Soil.

"The health of a soil as shown in its fertility is intimately connected with the kind of bacteria present in it. We are as yet in the dark as to the possible function of numerous groups of the soil organisms. Bacteriologists are seeking to discover their proper functions. A recent exhaustive study (1) of Actinomyces, or thread bacteria, in the soil seems to show that they serve to decompose grass roots, being more numerous in sod than in cultivated land. Other groups of bacteria undoubtedly must perform other important functions....

"..Fungi.

"Besides bacteria of all sorts, our cultivated soils are also teeming with fungi. The true function of the latter remains to be studied. There seems no doubt, however, that certain fungi like certain bacteria in the soil work on the organic and the mineral matter to make it available as plant food.....

"Nature and Function of a Healthy Soil Flora.

"The function of a normal soil is to provide available plant food. About 95 per cent. of the combustible weight of a growing plant is made up of carbon, hydrogen, and oxygen and nitrogen. The remaining 5 per cent. constitutes the mineral or the ash of the plant. Carbon, hydrogen, and oxygen are taken in the form of carbonic acid and water; nitrogen from nitrates produced by bacteria out of organic matter of the soil. The ash or the mineral elements of the plant are taken directly from the soil. Neither the organic nor the mineral elements are in a form which plants can make use of until they have been acted on by certain definite organisms of the soil.....

II. Sick Soils.

A. "Sick soils not influenced by parasites.

"We have seen that a normal and healthy soil is one in which the beneficial soil flora is at its maximum of normal activity, making the food of the plant assimilable. We have to discuss the abnormal or sick soils now. In this class we include those which are either physically or chemically so constituted as to have a detrimental effect on the activity of the soil flora; and those which are overrun with organisms directly parasitic on the plants grown in that soil. There are five classes to be considered in the first division.

"1. Denitrified Soils.

"This detrimental condition in the soil is brought about by a group of undesirable organisms, some of which are Bacillus ramosus, B. pestifer, B. mycoides, B. subtils, B. mesentericus vulgatus.....we have seen that the nitrifying bacteria oxidize the nitrogen and make it available for plants. In denitrification, the harmful bacteria tend to reconvert the available nitrogen into a non-available form, or else to liberate it into the air, where it may be considered as lost so far as the crops are concerned. Most trucking lands contain the nitrifying and denitrifying organisms in about equal proportions. To encourage the activity of the one over the other is the aim of intelligent trucking. The denitrifying bacteria thrive best in an abundance of carbohydrate foods. Fresh coarse manure with a high percentage of straw, when applied to the soil, will favor denitrification. It should therefore be avoided as far as is possible. There are, however, market gardeners who often use as much as fifty tons of such manure per acre in addition to a nitrate fertilizer. Such action is very likely to encourage denitrification because of the large amount of carbohydrates incorporated in the soil.....

"2. Nitre-sick soils.

"This form of sickness, peculiar to certain Colorado soils, was carefully studied by Headen (2) and Sackett (3). Nitre-sick soils are those which contain such large quantities of nitrates that they inhibit plant growth. Truck crops, grains, and fruit trees rapidly deteriorate on such lands. This condition occurs in a variety of soils in Colorado. It is met with in the light sandy loams as well as in the heavy clay loams, on lowlands as well as on hilltops. It is to be distinguished from true alkali troubles.

"The distinguishing characteristic of a nitre-sick soil is its brownish-black wet appearance. From afar the soil looks as if it has been wetted with crude oil; however the soil is usually dry. Sometimes the soil may be moist and slippery, due no doubt to the presence of large quantities of deliquescent salts. Walking through such a field produces a sensation similar to that which one would get from walking on cornmeal or ashes.....

"3. Acid-sick soils.

"Soils which contain an excess of acid in which crops refuse to grow, may be termed acid-sick. Acids in soils have a directly poisonous effect on plants. Soil acidity may be brought about by the loss of lime and other bases; and by the decomposition of organic and inorganic matter.

"Crops are known to draw heavily on the lime of the soil, and thus increase the proportion of acidity. This then is one direct way of depleting the soil lime. A ton of alfalfa, for instance, is known to take up 50 pounds of lime. With a yield of 6 tons per acre, the annual loss of lime per acre would be 2100 pounds.

"Lime and other bases are further lost from the soil by leaching. The soluble carbonates are but slowly soluble in pure water. However, carbon dioxide, nearly always present in soils, changes the calcium carbonate into calcium bicarbonate, which is rather soluble, and readily leaches out with the drainage water.

"Soils which are heavily manured are apt to become more acid. The decomposition of the organic matter yields large quantities of carbon dioxide which act on the carbonate in the manner above indicated. The annual leaching of lime from soils varies from 100 to 1000 pounds per acre.

"In addition to these causes, poor drainage has a tendency to increase the soil acidity. The application of ammonium sulphate as a fertilizer leads to a development of acidity by the production of sulphuric acid. The same is true when muriate of potash is added. In the process of nitrification in which nitrogen is made more available for plants, acids are produced.

"Acidity in a soil is usually characterized by a languid condition of the growing crop. Sorrels, poverty grass, broomsedge, cinquefoil, and redtop thrive best, and are generally indicative of acid soils. Not all truck crops are equally sensitive to soil acidity.....

"Treatment of Acid Soils.- The best remedy known is lime. Its effect is to neutralize the acidity, restoring the normal equilibrium for the activity of the soil flora, and thus enabling the plant to flourish. The amount of lime to be used depends largely on the kind of soil and the degree of its acidity.....

"4. Muck or Peat soils.

"Muck or peat soil is sick because most plants refuse to grow there unless it is properly treated. However, muck may be transformed into the best trucking land. There are States in the Union which possess muck lands by the thousands of acres. Yet these are the last to be reclaimed..... Peat itself is nothing more than rotten vegetable matter. Complete decomposition is impossible, because of the

absence of air and the accumulation of plant acids which contain antiseptic properties....

"Treatment of Peat soil: ...

"Drainage--The best methods of reclaiming peat soils is drainage.....

"Plowing--The second best method of improving peat soils is a proper working of them. Fall plowing is to be highly recommended. The peat is in this case exposed to the action of frost, rain, and snow, all of which helps in the more rapid decay of the organic matter.....

"5. Alkali-sick soils.

"The alkali problem is even of more widespread concern, as it affects nearly all irrigated districts of the arid and semiarid regions of the United States. An Alkali-sick soil is one which contains an excess of accumulated soluble salts which are injurious to plant growth. For convenience, alkali soils are divided into black and white. The black alkali lands are known to contain sodium carbonate or washing soda as the essential salt. The latter does not act so much on the soil as on the organic matter, turning it black. This black material is always found on the surface with the salts. The blackening of the soil, however, is not always an indication of black alkali. Many dark spots are found to contain the white alkali. Moreover, soils which contain little or no organic matter may contain large quantities of sodium carbonate and never turn black. The white alkali in reality is not a true alkali. The salts found in it are sodium chloride or table salt, calcium sulphate or gypsum, sodium sulphate, magnesium sulphate or Epsom salt. In addition to these may be found salts of potassium.....

"Effect of Alkali on Plant Growth.- Plants can stand the baneful effect of alkali only to a limited degree. The damage is always confined to the stem end. Here the epidermis turns brown for half an inch or more, gradually tearing away in a girdling fashion. This results in the collapse and death of the plant, which assumes a corroded appearance. The physiological effect of alkali is to plasmolize the cell contents of the bark....

B. Soil Sickness Due to the Presence of Parasites Harmful to plants.

"When a soil is sick because its beneficial bacteria do not perform their functions properly, or because of abnormalities in its chemical properties, careful treatment and proper cultural methods will restore it to health. But when a soil becomes sick and unproductive because parasitic forms gain a foothold there, much greater skill and knowledge are required to cope with the problem. Its solution is of the greatest economic importance to the trucker and gardner.

"Parasitic fungi finding their way in a soil do not necessarily interfere with the work of the beneficial bacteria, such as the ammonifiers and nitrifiers, for instance. Neither do they always influence the chemical or physical nature of the soil. They attack directly the crop itself. Of the numerous parasites rendering soils unproductive, we will consider here only two types.

"1. Soil sickness due to parasitic fungi.

"Fungi which produce Damping Off in seedlings.

"Fungi which produce damping off as well as Wilts, Blights, or Rots in plants.

"Damping off.

"Caused by Pythium de baryanum Hesse .....
(For a discussion of this trouble see under "Diseases caused by fungi-Phycomycetes" in Part II.)

"Other soil diseases.

"We have seen that Pythium de Baryanum is most active as a disease on young seedlings. Other fungi, however, may attack not only seedlings, but also older plants, in various stages of development. As a guide to the trucker and gardener, we shall consider two typical soil diseases, one which produces root rot, the other wilt only.

"Root Rot

"Caused by Rhizoctonia solani Kuhn.

"This fungus is of great economic importance because of its widespread distribution. It is capable of producing a damping off on a variety of seedlings, as well as of attacking older and mature plants.....

"There is perhaps no other parasitic fungus which is so widespread and capable of attacking such a variety of hosts as Rhizoctonia. The work of Peltier (4) shows that the following truck crops are susceptible to Rhizoctonia: Beet, bean, cabbage, cauliflower, celery, cowpea, cucumber, cress, eggplant, horseradish, lettuce, muskmelon, okra, pepper, radish, squash, sweet potato, garden pea, parsnip, potato, and tomato.....(See Potato Rhizoctonia in Chap. XX).

"Parasitic Soil Fusaria.

"Next in importance to Rhizoctonia is a group of fungi which belong to the genus Fusarium. Lands infected with these species of fungi become unfit for cabbage, potatoes, tomatoes, etc., causing great financial losses to the trucker. We will take up the specific troubles in studying each of these crops respectively.....

"2. Soils rendered sick by certain forms of animal life.

"The present discussion deals with the root knot, a disease produced by a little worm generally known as nematode, or eel worm.

"Root Knot.

"Caused by Heterodera radicicola (Greef) Mull.

"Root knot is most prevalent in light soils. This, however, does not exclude it from heavier lands where it may sometimes be found. The trouble is most widespread in the Southern States, where the winter is mild. In unprotected places in the North its numbers are probably greatly reduced each winter. The annual financial losses from this disease are staggering in extent. With proper culture and fertilization, however, a crop may be produced with practically very little loss where neglect would have caused a total failure. This is especially true under greenhouse conditions."- Taubenhaus, J. J.- Diseases of truck crops and their control. 1918. pp. 3 - 48.

Additional Examples of Soil Sickness.

Of the two general parasitic causes of sick soils mentioned previously by Taubenhaus, namely, fungi and nemas, or eelworms, the fungi compose by far the larger number of harmful species. In addition to the three important genera of sick-soil-producing fungi, Pythium, Rhizoctonia and Fusarium, described by the above author there are many others which at times cause serious trouble. Some of these are: Botrytis, Sclerotinia, Helminthosporium, Ophiobolus, Alternaria, Verticillium, Plasmodiophora, Chrysophlyctis.

Striking examples of soil sickness are: the "cabbage-sick" lands of Wisconsin due to Fusarium conglutinans; "onion-sick" soil, due to Urocystis cepulae; "flax-sick" soil inhabited by Fusarium lini; and the "wheat-sick" soil of North Dakota due to certain soil-inhabiting, wheat-infesting fungi.

Bolley (2) of the North Dakota Agricultural Experiment Station was one of the most energetic investigators of "soil-sickness" in connection with the wheat failures in that section of the country. The following quotation gives his views on this trouble:

"1. Constant or rather constant culture of wheat on the same lands bring about wheat-sickness, wheat-sick soil.

"2. Wheat does not thrive well in the presence of its own dead bodies, no matter how fertile the soil.

"3. Constant wheat cropping does not especially exhaust or use up the fertility, plant foods, more rapidly than crops in series.

"4. Best evidence indicates that constant wheat cropping does not introduce into the soil any permanent excrement or poisons detrimental to wheat.

"5. Constant wheat cropping tends to introduce with the seed, stubble, roots, etc., a number of wheat disease producing fungi. These fungi destroy, blight and rot off the roots of the wheat plants, and live internally in the straw and the seeds.

"6. These fungus parasites of wheat accumulate in fertile soils and bring about a condition of wheat-sickness, "Wheat-tired soil", which has led many to assume that such soils are in part or wholly exhausted for wheat.

"7. "Wheat-sick soil and wheat-sick seed are the chief causes of the trouble which millers complain of as deteriorated grain.

"8. The fungi attack the roots of the wheat, the leaves, stems, and young developing grains and produce many peculiar evidences of damage to the crop. They are the chief cause of the failure of wheat to properly stool on fertile soils. They make the plants live almost wholly upon the surface of the soil even tho the land is deeply and well worked. They cause the following peculiar features: wilting and blighting of embryos and plantlets in first leaf, 'Tip burn' and 'sun scald' of young plants at stooling time, blighting of side stool at shot-leaf period, black-foot or creosote colored stems below ground line; death of wheat in alkaline areas otherwise not sufficiently alkaline to injure the crop, incomplete filling of upper head parts, shrivelled grains, 'black-pointed' grains, purplish or pink grains, white-bellied grains, pie-bald grains, and play a large part in the troubles spoken of as 'bleached and blistered' grain.

"9. There are a number of these wheat fungi and together or severally they largely account for many anomalies of cropping. For example, some times fresh barnyard manures are particularly injurious to wheat even on rather poor lands. Sometimes the best methods of tillage fail to give plump wheat on good soils and under good weather conditions. Sometimes the most widely approved series of crop-rotation fail to produce wheat of proper grade under otherwise high culture and soil quality. Sometimes the most approved use of artificial fertilizers fail to give proper results even when applied to rather poor wheat soils. Finally, it is not at all uncommon for the best variety, best selected, best treated seed to fail to properly reproduce itself, even under high class soil, tillage and climatic conditions. These failures of the past may be explained by the fact that the root and seed diseases of wheat were present--introduced some times by the seed, sometimes by the fresh, uncomposted strawy manures, sometimes by wind-blown or water-washed dirt, etc.

"10. This disease theory rests on facts of nature. It helps to explain many good results which are sometimes noticed under intensive, proper, careful farming. For example: Proper summer working or soil tillage tends to firm down the soil and these wheat fungi do not develop rapidly or deeply in a firm compact seed bed. Such proper soil tillage keeps the upper layers of the soil stirred until the sunlight and aeration tends to purify the soil from the germs of the wheat diseases. The purified soil not only becomes more nearly free from weed seeds, but also largely free from the root destroying fungi. The wheat roots can then penetrate more deeply. Properly composted barnyard manures tend to become free from such

wheat root diseases. Properly selected, plump, bright colored, heavy weight seed grains contain less parasitic fungi under the bran layers than do the low grade shrivelled or water injured grains. The fanning mill, properly used, tends to discard grains which contain the wheat-sick fungi on the interior. Proper treatment of seed wheat not only kills smut spores, but kills the spores of the wheat root diseases which are commonly abundant on the exterior of even the highest grade wheat. Wheat which has been threshed before it is allowed to get wet makes better seed wheat than that which gets wet in the grain or sheaf, because such dry threshed, dry saved seed does not give the wheat-root fungi opportunity to grow under the bran layers of healthy seeds or grains.

"11. Wheat deterioration in the fertile wheat growing areas of Northwest America involves soil and seed problems directly analogous to those in the case of the flax crop or potato crop. It is not primarily a problem of soil fertility lost, but of disease present.

"12. Our "wheat-sick" soils are properly described by the word. They have not particularly lost their capacity to grow normal wheat. They will do it again when most of our farmers understand that proper wheat farming involves a proper sanitary handling of the soil and seed.

"13. Fertilizers and crop rotation will give a better account of themselves when the farmers sow purified seed on purified soil.

"14. The proper foundations for a crop rotation rests in the use of comparatively non-related crops in series,-- those which do not bear each other's diseases.....

"20. Deteriorated wheat, as seen in depressed yields and low quality, as now quite commonly produced in the great natural wheat-producing regions of this country, is not, primarily, a matter of lost fertility, or of modified chemical content of the soil, but is specifically a problem of infectious disease which is superimposed upon the problems of soil and crop management. Crop rotation, for example, is not, primarily, a farm process which is likely to conserve the fertility of the soil, but when properly arranged in a system so that the proper crops follow one another, it is definitely a sanitary measure tending to maximum p production.

"21. Wheat-root fungi and their spores are drifted from field to field and persist in the soil in exactly the same sense as weed seedssare distributed. This accounts for much new land infection.....- Bolley, H. L. Causes of soil sickness in wheat lands. N. D. Agri. College. Gov. Agri. Exp. Sta. Bul. 107. Dec. 1913.

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CHAPTER XI.

Plant disease control - Resistance and immunity.

From the standpoint of "immunization" as a method of controlling plant diseases all the control measures discussed in previous Chapters are mere expedients to which we must resort because we as yet have no better way of combating most plant diseases. If we could find or develop varieties of plants that would be immune to all diseases and at the same time possess all other desirable qualities, all our troubles would be over as far as plant diseases are concerned. While many notable successes have already been achieved by plant pathologists and plant breeders in the field of resistance and immunity, an enormous amount of work yet remains to be done before we can begin even to approach the final goal.

Why immunity is preferred to other means of control.

Some reasons why it is desirable to substitute resistant or immune varieties for the more susceptible ones are listed below.

(1) In some cases, as fire-blight of pears and stem rust of wheat, it has never been possible to secure adequate and satisfactory control by any of the ordinary practices in use.

(2) In some cases where control can be had by other methods the cost or other difficulties do not justify the practice.

(3) The treatment in some cases, while it may control the disease, causes injury to the host which offsets the gain derived from disease control.

Basis of immunity in plants.

Immunity to disease in plants has been explained largely on two bases. Formerly, perhaps, the most commonly advanced theory as to the cause of resistance was to the effect that some peculiarity of the morphological or histological structure of a certain variety of plant makes it less susceptible to attack by a specific organism than some other variety which does not have this particular morphological or histological character. At present, however, it is commonly conceded that, in the majority of cases at least, resistance or immunity is due to some physiological (15) or chemical peculiarity of the plant protoplasm or other cell contents. Perhaps sensitiveness on the part of the parasite to degree of acidity or alkalinity of the host cell, or delicate adjustment of the food requirements of the parasite to food content of the host cell may account for the difference in susceptibility of two varieties of the same species of plant to the same parasite. This problem is far from ultimate solution, however, and while there is a general tendency toward accepting the hypothesis that true resistance is physiological, yet there is some published evidence showing that in certain

specific cases resistance is not due to certain types of physiological factors. For example, Hurd (19) has shown that resistance in wheat to stem-rust is not related to acidity of the cell sap.

Disease resistant versus disease-escaping plants.

Sometimes it is rather difficult to draw a sharp line between truly resistant plants and those which might be called "disease-escaping".

The simplest example of "escaping" diseases in plants may be attributed to changes in the environmental factors. Weather conditions have great influence in decreasing or increasing the amount of infection. During a wet spring and early summer a susceptible variety of apple may develop a high percentage of scab whereas during a dry spring the same variety may develop very little scab. This does not mean that this apple is truly resistant to scab but that, due to conditions in this particular year, it "escaped" the scab to a great extent. Season has equal influence in this respect. A variety of wheat, which under favorable conditions is quite susceptible to smut, may, in some sections of the country, "escape" smut infection if sown either earlier or later than the usual seeding time.

The question might be raised as to whether plants which depend upon some histological or morphological character for their resistant qualities are really resistant or simply "disease-escaping". For example, does the difference in thickness of the cuticle in varieties of carnations (12) determine their resistance or susceptibility, to rust, or does it simply enable some varieties to "escape" the rust more readily than others? Again are those varieties of wheat which have closed flowers (12) really resistant to loose smut or are they just more likely to escape the disease because of this character? Some would perhaps extend the use of the term "disease-escaping" to include plants which remain free from disease for any reason other than on account of the peculiar physiological or chemical make-up of the living cell. This would reduce all true resistance or immunity, then, to a question of chemical bodies in the host plant.

This subject is further elucidated by the following quotation from Freeman (1):

"The essential character of true resistance as pointed out by Ward, Salmon, Biffen, Orton and others lies in a protoplasmic activity and is independent of inoculation accidents. A variety may escape a disease through certain peculiarities of physiologic host activities, of meteorological conditions, or even of certain morphological host characters. The latter is well illustrated by the following experiments of the writer. A variety of barley was grown in different soils provided by Harter of the U. S. Department of Agriculture during his alkali soil investigations. These soils varied from the normal garden soil to those containing about 2% of alkaline salts. Plants in the different soils when inoculated by spraying methods in the greenhouse showed different amounts of rust, in general those in the stronger alkaline soil showing less rust. The latter, however, when attacked exhibited large and vigorous growths of the rust. The smaller percentage of pustules was undoubtedly due to the greater development of "bloom" on the barley foliage when grown in the strong alkali, resulting in the

rolling off of the water drops, and hence in the loss of the inoculating material. Harter has shown that the plants in the different soils exhibited measurable differences in the thickness of the outer epidermal walls. The bluish color of the plants in the alkaline soils and the greater tendency of the water drops to run off were quite pronounced. There seems to be no reason for assuming that there was any difference in real rust resistance. Again Ward has shown that wheat rust uredo spores may send germ tubes into the stomata of plants of many different genera other than barberry, wheat or other grasses, and that they may even produce a rudimentary mycelium but they fail to penetrate the protoplasmic defense of the mesophyl and soon succumb."

Means of securing resistant or immune varieties.

At present there are only two practical ways of securing varieties of plants which are disease-resistant. These are: (a) by selection and (b) by hybridization.

Selection.- It has been noted that in nearly all cases certain varieties of plants are more resistant than other varieties of the same species to a specific organism. For example, certain varieties of wheat are much less susceptible to smut than other varieties. Some varieties are even practically immune. Again certain individual plants within a variety prove to be more resistant than other individuals in the same variety. It is a comparatively easy matter to select these resistant varieties or individuals from which to grow future crops. In the case of annual plants the continued selection and propagation of resistant individuals may result, in a relatively few years, in a strain which is strongly resistant or perhaps immune. In the case of perennial plants such as trees the process is necessarily much slower and with fruits that are propagated by vegetative means, as grafting, it may not be possible to accomplish much by this means.

Hybridization.- Sometimes the process of selection alone does not result in the type of plants desired. Perhaps when the investigator finds a variety or an individual which possesses the desired resistance to disease he discovers that other desirable qualities are lacking. He may find a variety of wheat immune to smut but this wheat may be good for nothing after all. It may be a poor yielder, have very poor milling qualities and many other undesirable characters. But if it is truly immune to smut he may be able to cross it with a variety which has all the other desirable qualities and thus finally breed up a strain which is satisfactory in all respects including immunity to smut.

Genetics of immunity.- In order to go far in the process of securing immune varieties by hybridization one should have some training in genetics and plant breeding. Resistance and immunity are subject to the laws of heredity. For example, Biffen (2) found that in case of certain varieties of wheat which are resistant to stripe rust (Puccinia glumarum), rust resistance is a unit character which, in crosses between resistant and susceptible varieties, behaves as a recessive Mendelian character.

Armstrong (4) also worked with stripe rust and some of his findings are quoted below. He stated:

"That susceptibility and immunity behave as unit-characters, and depend primarily upon definite factors which are inherited according to the simple Mendelian law."

"That segregation leads to the occurrence in the F_2 generation of susceptible and immune individuals in the proportion of 3: 1.

"That the immune F_2 plants breed true to that character.

"That one-third of the susceptible F_2 plants are homozygous for susceptibility and breed true, and that the remaining two-thirds are heterozygous for susceptibility and give rise to offspring in which rusted and rust-resistant plants occur as in the F_2."

Melchers and Parker (5) made crosses using three varieties of winter wheat which were resistant to a strain of stem rust (Puccinia graminis tritici) and three susceptible varieties of spring wheat. On testing succeeding generations resulting from these crosses they found that, with these varieties, resistance is dominant and susceptibility is recessive.

It will be noted in the cases cited above that rust-resistance is a recessive character in one instance and a dominant character in the other. This seems to indicate that there is no uniform rule governing the inheritance of disease-resistance in plants.

There is a vast accumulation of literature dealing with the problems of genetics in general and a goodly percent of these publications deal with the particular problems of breeding plants for resistance to plant disease. The list of titles among the references at the end of this Chapter will serve to indicate some of the various problems connected with investigations of this kind.

Difficulties met in developing resistant varieties.

The investigator who attempts to develop resistant or immune varieties of any particular crop to any specific disease is likely to encounter some difficult problems before he can hope for complete success. There are at least three of these serious obstacles, any one or all of which must be met and overcome before satisfactory varieties can be developed by selection and hybridization. These are (a) the fact that immunity to disease is by no means necessarily associated with other desirable qualities in a particular variety, (b) that a plant may be found which is resistant to one disease but very susceptible to another disease of equal or greater danger, and (c) the fact that there are, in many cases, several biologic strains of the same organism and while a variety of the host may be resistant to certain strains, it may be very susceptible to another strain or strains.

(a) Immunity must coincide with other desirable characters.

Reimer (13) found certain varieties of chinese pears which were practically immune to fire-blight but these pears were of no commercial value. His problem was to use these varieties of pears as a basis for building up a pear that would

be immune to blight and at the same time have a high commercial value. It is manifest that this is likely to be a much more difficult task with the pear than a similar problem with some annual or biennial plant such as bean, corn, cabbages, etc., would be. As is well known pears are ordinarily propagated vegetatively by budding or grafting and the only way to secure any immediate results from the immune varieties is to use them for grafting or budding stock on which to grow the commercial varieties. The alternative is to hybridize and trust to luck that after many years waiting a seedling may fortunately be found which will combine the characters of blight resistance and commercial desirability.

(b) Immunity to two or more diseases not usually coincident.

A variety of apple which is resistant to scab may not necessarily be resistant to fire-blight, blotch or black-rot. A variety of wheat which is resistant to smut may be susceptible to stem rust. As an exception to the rule it may be noted that a variety of cowpea has been developed which is resistant to both wilt and root knot. It may be stated, however, that it is the exception rather than the rule that this coincidence occurs. When we take the above facts into consideration along with the fact that our crop plants are nearly always subject to more than one disease and sometimes very many, as, for example, the potato, it becomes evident that the problem is greatly complicated. Even if a variety were developed which exhibited resistance to one disease the chances are that it would be susceptible to other diseases of equal or greater seriousness.

(c) Biologic races.

Evidence has been accumulating for many years that many, if not all species of plant pathogens are composed of more than one strain or variety. Perhaps the most classical example of this phenomenon that we have today is that of the black stem rust of wheat. Not only has it been shown that this species (Puccinia graminis) has a separate strain for wheat, oats and rye, but that the wheat strain can again be subdivided in many different strains or forms. Stakman and Levine (17) stated in 1922 that there were then known thirty-seven different biologic forms of the stem rust fungus. Leach (18) found at least eight distinct biologic forms of the bean anthracuose fungus (Colletotrichum lindemuthianum).

It can readily be seen that the existence of so many different forms of a species of parasite complicates the situation very greatly when an attempt is made to select or breed a resistant variety of the host plant. If a variety should be selected or developed which proves resistant to a certain strain of the parasite, there is no assurance whatever that this variety will also be resistant to all the other strains or biologic forms of the organism. However, in spite of all the difficulties enumerated above it still remains true that the development of resistance and immunity in plants offers a wide field for research and constitutes the only avenue of approach for the control of certain plant diseases.

"Artificial" immunization.

The question is frequently raised as to whether plants can be immunized to disease in the same manner that animals and man are rendered immune to certain diseases by the use of serums or the production of anti-bodies. No progress has yet been made in this direction and it is doubtful if this can ever be done with plants as it is in the animal kingdom. The structure of plants is so different from that of animals, especially as regards a circulatory system, that it does not seem likely that much success can ever be attained in that direction. In so far as can be predicted at the present time it seems probable that the attainment of immunity in plants will have to come through selection and hybridization as discussed above rather than through the administration of serums or any means now used in human medicine.

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CHAPTER XII.

Plant Disease Control: Relation of Insects to Plant Diseases.

For a number of years evidence of the insect transmission (and possibly also hibernation in a few cases) of plant diseases has been increasing by leaps and bounds until at the present time this question has become one of the major problems of plant pathology. The literature of the past twenty or thirty years, and more particularly of the last decade, abounds in references to the part played by insects in transmitting plant diseases from host to host.

Rand and Pierce (1) have recently given a rather comprehensive resumé of this whole subject in an article entitled, "A coordination of our knowledge of insect transmission in plant and animal diseases." Following is a condensed outline of their article, some parts being quoted verbatim and others abstracted more or less briefly:

"General relations of insects to parasitic diseases.

"There are many conditions of disturbed function or anatomy caused directly by insects or other small animals without the intervention of parasitic microorganisms. Such, for instance, are the local irritations resulting from the bite of the tick, flea, spider, or mosquito, and the various dermatoses caused by lice, chigoe, red bug, and mites, among animals; and the various forms of erinose and stigmonose, and many insect galls, among plants. Some of these conditions may as truly be included under the heading of disease as disturbances caused by microorganisms, but they scarcely come within the scope of the present paper.

"Setting aside, then, such cases of disease as are of direct insect causation, there are three general relations which an insect may bear toward diseases due to microorganisms. The infective principle (1) may be picked up by the insect on external parts of its body, such as the legs or outer mouth parts, where it may retain its virulence for a certain period of time. In these cases the organism may be (a) directly inoculated, as into wounds made by the insect carrier, or (b) accidentally sown from its body under such conditions that infection follows. Such purely mechanical dissemination may be the means of spreading infection over a wide territory.

"Again, (2) an insect without itself carrying infection, may cause wounds through which parasitic microorganisms find easy access to the plant or animal body, brought there by other agencies.

"Furthermore, (3) microorganisms are often taken up by an insect during the feeding process and passed along unharmed through the alimentary tract. If the infective principle (a) is merely taken into the body of the insect, and, without change or multiplication, passed out in a normal way, this mode of dissemination may be spoken of as mechanical internal transmission. If, however, the infective principle (b) develops or multiplies within the insect body, or by its own movement

goes counter to the usual course of substances through the body and finally arrives at a point from which it may be successfully transferred to its alternate host, the mode of dissemination is designated as biological internal transmission."

I. External transmission of parasitic microorganisms.

A. External dissemination and direct inoculation by the insect carrier.

Bacterial diseases.- One of the most extensively investigated bacterial diseases of plants is the fire-blight of pomaceous fruits caused by Bacillus amylovorus. Many workers (see references at end of chapter) have stated that insects such as tarnished plant bugs, bees, wasps, flies, aphids, leaf-hoppers, curculio, bark-borer, red-bugs, and pear psylla carry the blight organism. It has been demonstrated satisfactorily that many of these insects actually do carry the germs, and inoculate them into the host through bites or puncture of their own making. The germs are carried externally on the mouth parts, feet or other part of the insect's body.

The wilt of solanaceous plants (Bacterium solanacearum) has been transmitted by the Colorado potato beetle.

Cabbage worms, various bugs, beetles and aphids are said to transmit the cabbage blackrot organism, Bacterium campestre.

The bacterial blade blight of oats is distributed and inoculated by two species of aphids.

A bacterial rot of lettuce is transmitted by aphids.

Fungous diseases.- The lima bean mildew (Phytophthora phaseoli), brown rot of stone fruits (Sclerotinia fructigena), larch canker (Dasycypha calycina), blackleg of cabbage (Phoma oleracea) and the apple canker fungus (Nectria) are examples of fungus diseases said to be transmitted externally on insects and inoculated by them into the host.

B. External dissemination and accidental infection without direct inoculation.

In some instances insects act strictly as mechanical carriers, transplanting the infective principle to a new host but not inoculating it into the host.

Bacterial diseases.- In animal pathology typhoid fever and cholera fall into this class.

Among bacterial diseases of plants fire blight may also fall into this class as well as the previously mentioned class. Some insects which do not bite or puncture the host may transplant the germs to pruning cuts, hail injuries or other wounds.

Fungous diseases.- Spores of some rusts, smuts, bitter-rot of apples, the chestnut blight fungus, late blight of potato and beet leaf spot are thought to be carried by insects sometimes.

II. Infection through insect wounds without dissemination by the wounding agent.

"Many instances are on record, particularly among plant diseases, where insects are not directly concerned in transmitting the causal microorganisms, but where injuries which they initiate afford the necessary openings into the host body through which infections later take place."

Bacterial diseases.- Angular leaf spot of cotton (Bacterium malvacearum) and a disease of sugar beets caused by (Bacterium aptatum) are said to enter through wounds made by insects or other agents, although the organisms are not carried by the wounding insect.

Fungous diseases.- Some fungous diseases which may gain entrance through insect wounds are: onion blight (Peronospora schleideni), chestnut blight (Endothia parasitica) and pecan scab (Fusicladium effusum).

III. Internal transmission of parasitic microorganisms.

"The internal forms of disease transmission, in which the parasitic microorganisms either (1) go passively through the insect body or (2) persist and multiply within the body, present greater difficulties for study and demonstration. Furthermore the same organisms that pass through the insect's body are in a large number of instances also carried externally, showing that here, as in all phases of biological science, no hard and fast lines can be drawn. Indeed, it is not only possible but probable that in many diseases where only external carriage has hitherto been proved, later researches may demonstrate that one form or the other of internal transmission also takes place.

"The simplest method of internal transmission is that in which the organisms merely pass through the body of the insect in the ordinary course of food materials. There are two ways in which microorganisms may leave the body under these circumstances. Many insects are provided with a crop which serves as a storage sac, and such insects commonly regurgitate a part of the contents in order to moisten their food or sometimes as vomit after overfeeding. Ants regurgiate their food in order to feed their young. There are also certain insects that exude liquids from other parts of the body, as in the aphids where honey dew is excreted from nectar tubes. No one so far has demonstrated the liquid excreted from these nectar tubes of aphids to contain microorganisms taken up by the insect, but it is not impossible, and is a question that should be investigated. The ordinary course, however, is for ingested materials to pass through the alimentary tract and out at the anus.

"In human and animal diseases there is an abundance of evidence that disease-producing microorganisms can be taken up by an insect and regurgitated in an infective state. The house fly vomit spots have been repeatedly proved to contain infective germs even for a considerable time after ingestion.....

A. Mechanical internal transmission.

"In the mechanical internal type of insect transmission the infective principle remains viable after passage thru the alimentary tract but undergoes no appreciable multiplication or development within the insect body. Only a passive relation exists here between insect and microorganism."

Bacterial diseases.- The bacillus which causes bubonic plague is capable of remaining alive in the intestines of flies for 48 hours and in rat fleas for three weeks. Fleas inoculate man with the disease.

Fungous diseases.- The spores of several species of parasitic fungi are capable of passing through the intestinal tract of insects in a viable condition. Ergot, white pine blister rust, early blight of tomatoes (Alternaria solani) and wilt and fruit rot of raspberry (Leptosphaeria coniothyrium) are examples of diseases the spores of which may be carried internally in insects.

B. Biological internal transmission.

"In the biological type of transmission the infective principle finds within the insect body conditions favorable to its development and multiplication. In this way the duration of the period of infectivity becomes greatly lengthened, and likewise the difficulties of observation and demonstration are much increased. Many of the protozoan and so-called filterable virus diseases and a few bacterial and fungous diseases have been shown capable of this prolonged existence and multiplication within the insect. It is relative to this type of insect transmission in both plant and animal diseases that some of the most careful and extended investigations have been carried out."

Bacterial diseases.- In some cases it appears that the typhoid fever bacillus can survive for long periods of time and apparently multiply in the house fly. The bacterial wilt of cucurbits (Bacillus tracheiphilus) seems to belong to this class being carried by certain beetles. The olive-knot organism, Bacterium savastanoi and the coconut bud rot organism, Bacillus coli may also belong here.

Fungous diseases.- Certain yeasts and molds are said to live in the intestinal tract of some insects.

Protozoan diseases.- In man some examples of this type of insect transmission are found in malaria which is carried by mosquitoes, the diseases transmitted by the tsetse fly in Africa, and the sleeping sickness caused by Trypanosoma gambiense.

An example of a protozoan plant disease is found in a "flagellosis" occurring in the latex or milk-vessels of species of Euphorbia in the spurge family.

Filterable contagium diseases.- "Among both plants and animals the so-called filterable virus diseases are of fairly common occurrence. Some of the diseases formerly classed as 'Filterable virus' diseases have since been demonstrated to be due to parasitic microorganisms. In all this class of infections the method of contraction and the sequence of signs or symptoms give a 'clinical picture', so to speak, of a parasitic disease. The only difference is that in the 'filterable virus' diseases the causal contagium has thus far eluded our microscopical and cultural methods.

"Among animal diseases of this type yellow fever is a well known example. This dread scourge of the tropics is borne by mosquitoes, and the ultimate contagium will pass through the pores of a Berkefled filter. The contagium of yellow

fever circulates in the blood stream of a patient for at least three days after the initial chill. To become infected a female Aedes mosquito (Aedes calopus Meig.) must bite a fever patient during this first three days, whereupon a latent period of twelve days must then elapse before the infected mosquito can transmit the disease. Injection of blood from a fever patient during the first three days will induce the disease in a non-immune person; otherwise the only known method of transmission is through the bite of this mosquito. (Noguchi, through careful and extended investigation has recently shown yellow fever to be due to Leptospira icternoides Noguchi. This serves only to emphasize the statements made in the preceding paragraph."

Among plants the curly-top disease of sugar beets and the mosaic of numerous species of plants have been proven to be carried by insects. The beet leafhopper is said to carry the curly-top "virus" and this insect seems able to retain the infective principle for several months after feeding on diseased plants, probably living over on wild plants which are susceptible and transmitting the disease back to the sugar beet in the spring. Aphids seem to be the chief insects concerned with transmitting mosaic diseases. In case of a "virus" disease of spinach (blight) it was shown that aphids, after feeding upon diseased plants, transmitted the "contagium" to their off-spring even to the fourth generation, which in turn could carry it to a new host upon which they chanced to feed. Even after molting, a "virus-bearing" aphid retains the power to infect. This shows that the contagium is carried internally.

Conclusion.

"The literature on plant diseases transmitted by insects is thus seen to be fairly extensive, and the importance of insects as disseminating agents becomes from year to year more apparent. In fact, the investigations of the past three decades have completely revolutionized our view of the role of insect transmission in both plant and animal diseases. However, in many cases authentic information is still lacking as to the exact methods of inoculation and transmission, and in some instances too much is left to inference and circumstantial evidence; but enough really good work has been done to show an exact correlation between the findings of plant and animal pathology. Furthermore, it is not to be doubted that future work will fill up many of the existing gaps in our knowledge and will add greatly to the list of insect borne diseases."- Rand, F. V. and W. D. Pierce. A coordination of our knowledge of insect transmission in plant and animal diseases. Phytopathology 10: 190-220. April, 1920.*

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* Note.- For a complete list of references covering the facts presented in the work of Rand and Pierce (1) quoted and abstracted above, see the list of of literature cited in their original article. A partial list of references will be found at the end of this chapter.

Number of diseases transmitted by insects.

According to Rand (2) the number of plant diseases now known to be insect transmitted are as follows:

Bacterial diseases.- There is full proof for nine diseases and circumstantial evidence for seven more with one doubtful case.

Fungous diseases.- Definite proof for sixteen diseases and strong evidence for twenty-five more with one case doubtful.

Protozoan diseases.- Only one case of protozoan disease in plants is definitely known and this has an insect as intermediate host.

Virus diseases.- Insect transmission has been proven in case of fifty-nine different hosts for the mosaic diseases, and strong circumstantial evidence exists in seven other cases.

Systematic relations of insect carriers.

Ball (2) reminds us that in a certain type of insect transmission the act is entirely accidental. For example, in fire-blight any insect that chances to come in contact with the bacterial ooze may carry the germs to another host. There is no special adaptation of any kind. On the other hand, in diseases like curly-top of beet, only a single species of insect is able to carry the contagium and it requires a definite incubation period in the insect.

Problems connected with insect transmission of disease.

Gardner (2) in discussing this problem concentrates his attention largely upon the virus or mosaic diseases as being the largest and most serious group wherein insect transmission is widely prevalent. He states that in some phases of this work there is need for cooperation between plant pathologists and entomologists while in other phases the task must fall entirely upon the entomologists. Some of the problems suggested by Gardner follow:

"In many cases we know that mosaic transmission is accomplished entirely by certain species of aphids or leafhoppers. The obvious necessity in these cases is a really effective control for these particular species, not the degree of control which would be considered satisfactory from the standpoint of actual insect damage, but an absolute control, because one aphis or leafhopper alone may be able to inoculate a plant.

"Might not more detailed study be concentrated upon the particular insect species already incriminated as carriers? Such a study should disclose important features in connection with the life history of these carrier species under the particular local conditions where the disease occurs, such as the effect of

"Is infection caused by the bite or feeding puncture or by oviposition? What is the localization of the virus on or in the insect's body? Is it external as on the feet or mouth parts, or is it in the saliva or alimentary canal contents?.....

"Why do various species differ in their transmitting ability? Is this correlated with feeding habit and type of tissue punctured or with inability of the virus to endure conditions in or on the insect?"....- Gardner, M. W. Insects as disseminators of plant diseases. IV Urgent problems of the future. Phytopathology 12: 237-238. May, 1922.

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CHAPTER XIII.

Plant disease control: Storage and transportation problems.

When speaking of plant diseases and their control it is customary to think in large part, if not entirely, of growing crops in the field. But by no means all crops are safe from disease when harvested. Indeed with a great many plant products the menace is as great or greater after they are harvested. Enormous losses are sometimes sustained in certain kinds of products, especially fruits and vegetables, after they are placed in storage or while in transportation, or even after arriving at the market. Most of the losses occurring in storage or transportation are due to organisms of decay. However, there are some purely "physiological" troubles, that is, diseases which are not due to any organism whatever, that develop in storage and transportation.

Link and Gardner (1) cite a few instances of the enormous loss occurring in transit. During the 1918 season a loss of $1,250,000, or 2500 carloads of watermelons was suffered in the shipments from four states. In one week 2500 hampers of Louisiana head lettuce were rejected at the car in Chicago. Cuban pineapples commonly suffer losses of 15 to 25 per cent on account of Thielaviopsis rot.

Some of the factors which must be considered in a study of the disease problems related to storage and transportation are suggested in the following outline:

I. Parasitic diseases.

A. Types of injury (Link and Gardner (1) list the following three.)

1. "Those in which the lesions may constitute objectionable blemishes without causing actual unsoundness (radish blackrot, potato scab, onion anthracnose, cucumber mosaic).

2. "Those in which the lesions may serve as ports of entry for rot-producing organisms (bean blight, cucumber bacterial spot, tomato nailhead spot, tomato blossom-end rot).

3. "Those in which the lesions may enlarge, under transit conditions, due to the invasion of sound tissue by the original organism, resulting in extensive rots (tomato phoma rot, bean anthracnose)."

B. Time and place of origin.

1. In the field before harvesting.- With many diseases inoculation may take place before the crop is removed from the field but evidence of the trouble may not show up at all or only slightly until the product is in storage or in transit. Apple anthracnose rot and apple scab may develop slowly after the fruit goes into storage, probably having been inoculated while still in the orchard. Brown rot of peaches may develop rapidly in transit, even though the fruit seemed sound when it left the trees.

2. In storage or transit.- While many diseases which become evident in storage or in transit really have their origin in the field, there are others which may originate in storage or in transit. Rhizopus and Penicillium rots are examples of this type.

C. Contributing causes of infection.

1. Lack of control measures in the field.

Those diseases which originate in the field must be combated by the usual control measures applicable in the field. Neglect in this respect is apt to result in storage or transportation losses.

2. Careless handling.- Infection by many of the rot organisms cannot take place in perfectly sound fruit. Careless handling in harvesting, hauling, packing or stowing operations is sure to result in many bruises and wounds on fruits and vegetables. These injuries offer an opening to many organisms which otherwise would be harmless.

3. Lack of sanitation.- After housing a batch of diseased stuff, warehouses and cars should be thoroughly disinfected before bringing in fresh clean stock. Bacteria and fungus spores are apt to remain for some time in the storage quarters or carriers and are a menace to fresh produce placed therein.

D. Environmental factors.

1. Temperature, humidity and ventilation.- The growth of fungi and bacteria is generally favored by high temperature and humidity. Practices which keep down the temperature and humidity retard the development of diseases. Ventilation is a factor in controlling temperature and humidity.

Temperature is a very important factor in the development of plant diseases in general. For a general discussion of this topic see Chapter V. An example of the effect of temperature as applied more particularly to storage and transportation problems may be of interest here.

Ames (4) studied the temperature relations of certain organisms which cause rots of fruits and vegetables. She found that Monilia and Penicillium germinate at 0°C., but make very little growth at that temperature. Rhizopus, Thielaviopsis, Glomerella and Cephalothecium, do not develop below 5°C., but can continue to grow at that temperature provided growth has been started at a higher temperature. None of these organisms except Rhizopus is able to germinate above 36°C. The optimum temperature for Penicillium and Monilia is 25°C. for Cephalothecium, Glomerella and Thielaviopsis is 30°C., and for Rhizopus 36°C. The thermal death point of Penicillium is 58°C. of Rhizopus 60°C. and of the rest between 51°C. and 53°C. She concludes that: "The results indicate that in refrigerating experiments, temperatures near zero must be maintained if development of rot producing fungi is to be entirely avoided. From the effect of the exposure to low temperatures on the germination of the spores, one can also conclude that the conidial forms of fungi are much more resistant to cold than is commonly supposed."

II. Non-parasitic diseases.

A. Environmental factors.

Non-parasitic diseases in general are due to environmental factors. Many of them such as bitter-pit, cork and drouth-spot of apples, internal brown spot of potato and point-rot of tomato have their origin in the field and cannot be called storage troubles. Certain others, such as apple-scald and potato black-heart, are distinctly storage or transportation troubles.

1. The temperature factor.- Blackheart of potato (5) is a disease which is considered largely due to high temperatures although ventilation may play a part also. On the other hand too low temperature may result in losses from freezing injuries of various kinds (7, 8).

2. The ventilation factor.- Apple-scald (6) is due to the accumulation of certain gases (esters) resulting from the metabolic processes going on within the stored fruits. Proper aeration removes these gases and prevents scald. (See more detailed discussion of this disease in Part II.) Temperature also plays a part here in that the rate of respiration and other metabolic activities of the fruit is dependent to some extent on temperature relations.

Special application.

Perhaps the principles outlined above will seem more real if applied to actual conditions in the business world. Coons and Nelson (3) have studied the problem of decay of fruits and vegetables in shipments for the American Railway Perishable Freight Association and sum up the situation as follows:

"The Cause of Decay in Shipments.

"The packing of infected produce.- Fruits and vegetables decay in shipment due to the activity of fungi and bacteria. Some of these fungi and bacteria are the parasites which are capable of causing disease in the field. In many cases, partially decayed fruit or vegetables are packed. These are cases of incipient diseases. Some fungi which appear only as a cause of blemishes in the field, are sometimes found under the conditions of shipment to increase enormously or to open the way for severe rotting. In many cases the decay in the car is merely the outcome of a latent infection which started in the field. Such fruits and vegetables are diseased when loaded in the car and they never improve. Rotting fruits and vegetables are notorious in bringing about conditions which promote infection of neighboring plants and in furnishing the inoculating material as well.

"Infection within the car.- Again, infection may take place in the car as a result of the conditions there presented, and although this decay arises from the same fungi as cause diseases in the field, and although the spores lodged upon the fruit or vegetables in the orchard or field, such a case must be carefully distinguished from the types of infection previously mentioned.

"Bruising, and rough handling.- The most prolific cause of decay in shipments is the group of weakly parasitic forms which are completely excluded by the unbroken skin of the plant, but which quickly cause rot when once the skin is broken or bruised. To this group of decay-producers the great bulk of losses may be attributed. Rough, careless handling either in picking or packing, or by the carrier is, therefore, responsible for the large percentage of our losses.

"The breaking down of natural resistance due to car conditions.- There is still another class of decay-producing organisms. These are fungi and bacteria which are not parasites at all; such organisms when inoculated into the healthy living fruits or vegetables do not produce disease. Yet such organisms in many shipments bring about, more rapidly than is normal, what is called "inherent decay". All are familiar with the fact that apples will keep well in the cellar until late winter. The fruit becomes more and more mellow. Then comes a period when the fruit rapidly decays--molds attack through the sound skin, and around the stem end. It would seem that a certain maturity was reached and the cells began to lose their tone, perhaps to die. The native resistance disappears and the fruit decays rapidly. In this illustration we have a parallel to what is frequently seen in shipments. Due to conditions in the car, period on the road, or age of the plants when shipped, etc., the resistance of the host suddenly breaks down and the car becomes a mass of rotted produce....

"The Problem of the Elimination of Waste in Shipments.

"Find the cause.- The elimination of wastes in shipments depends fundamentally upon the discovery of the causes of the losses. In the preceding section several groupings were made of the causal factors. With the discovery of the cause of loss usually comes the fixing of responsibility.

"Prevent claims instead of fighting them.- The fixing of responsibility should not end the matter. It is often the case that the shipper is just as well satisfied to realize on a claim as he is to sell at the market. It is claimed that some firms make a practice of collecting a high-grade price on second-grade fruit, paying the farmer only a pittance. On the other hand, the railroad cannot be satisfied with being able to fight claims successfully. It has the larger duty of preventing claims if it expects those along the line to prosper.

"Educate the shipper.- If the cause of a loss is a plant disease which begins in the field and which can be prevented by proper control measures by the farmers and fruit growers, this fact must first be established. Then no effort must be spared to enlist the services of all concerned in the doing away with this needless condition.

"The colleges and experiment stations have for years taught the proper methods for controlling fruit and vegetable diseases. They speak to large groups, and those whom the college extension forces reach soon learn to avoid trouble. On the other hand these educational forces do not ordinarily have the intimate relation with the man having trouble that the market man or the carrier has. The railroad and commission man can reap great returns if they will assist in bringing the teachings of the college to their customers.

"Care in handling is first essential.- Much of the loss comes from careless handling in picking or packing. Without exception it may be said that the first essential for shipment is freedom from wound or bruise. Fruit must be picked without bruise, cut or injury, carefully handled in the various grading operations, and carefully packed by experienced and careful packers. Mold fungi are always present on fruit and the least bruise or wound may open the avenue for them.

"Eliminate losses due to faulty stowing, etc.- If the cause of loss depends on conditions in the car, be it faulty packing, stowing, bracing, lack of ventilation channels, overloading, these must be remedied. The railroad cannot be satisfied with a mere notation on the billing which will protect it. Better business demands that losses be prevented. The railroad must educate its shippers.

"Train the inspectors.- If the cause of loss is due to faulty icing, faulty car construction, etc., these should be readily avoided. The inspection service on most railroads needs an overhauling or checking.

"In self protection all railroads should have some definite system, such as has been developed on some lines, for proving that icing service has been performed according to instruction. This system should make possible accurate determination as to the condition of the car in respect to position of ventilating devices and contents of bunkers at the time of arrival at all icing stations and at destination as well. It should also afford complete record of the quantity of ice added at all icing stations, as well as the time at which this service was performed.

"Prof. Stevens of the University of Illinois, made an admirable start when he established a short course to teach the facts of plant disease in relation to transportation. Men so trained become doubly valuable in the handling of shipments. Their reports become intelligible documents available for claim decisions and their recommendations can become the basis for a rational program of improvement.

"The Bureau of Markets.- The method of shipment, the demands as to icing, ventilation, containers, etc., present a very important problem. This matter has been solved very satisfactorily for citrus and for many other fruits. The Bureau of Markets is very actively engaged in exactly this line of work. It is not too much to expect that the efforts of the scientists of the Bureau will modify and improve present practices and give us a working body of recommendations.

"Pack a worthy product.- The problem of elimination of loss is an enormous one and touches the shipper, the market man, and the carrier. Each must work for the greatest good, if the growing needs of the public are to be met. But there is no method of handling, icing or marketing which will overcome the effects of a lack of integrity of the producer or shipper. This is fundamental. Goods of high quality, free from disease, properly packed mean safety; the other sort--hazardous business."- Coons, G. H. and Ray Nelson. The plant diseases of importance in the transportation of fruits and vegetables. Cir. No. 473-A. American Railway Perishable Freight Association.

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CHAPTER XIV.

Unsolved problems of plant pathology.

In spite of the enormous amount of investigational work that has been done by plant pathologists in the past and the large number of plant diseases that have been described and more or less completely worked out in all details, there still remain many problems for future solution. Some of the lines of investigations demanding attention are listed here. (1) Life history studies amongst the parasitic diseases have long been a favorite pursuit of the plant pathologist and a vast amount of this type of work has been accomplished. But there still remains much to amplify in many cases. The manner of hibernation, dissemination and infection is not completely understood in many diseases. (2) The field of study in the pathological histology of diseased tissues has by no means been exhausted. (3) There is great need for studies of "epidemiology" or epiphytotics, that is, sudden and severe outbreaks of disease. (4) Ecological studies would undoubtedly throw much light upon the why and the wherefore of many puzzling pathological problems, especially the seasonal eccentricities of many disease outbreaks. (5) Biologic specialization or the occurrence of biologic races of parasites offers a great field for interesting and instructive research. (6) Resistance and immunity offers one of the most important avenues for plant disease control. We have only begun to scratch the surface in this phase of plant pathology. (7) At the present time the so-called "virus" diseases, as illustrated by mosaic hold the center of the stage and hurl the strongest challenge to the plant pathologists that they have met in many a day, if ever. (8) The non-parasitic diseases still offer many unsolved problems, especially as to causal relations. (9) Lastly, but not least, there is still great room for improvement in fungicides and their application. Also the question of fungicide injury to the host plant is important.

In 1917 Stevens (1) gave a good resumé of this whole subject and practically everything he said at that time still holds. The main parts of his article are quoted below.

"Plant pathology is primarily and essentially an economic subject, and it is mainly from this viewpoint that it will be considered in this paper, attention being called also to the relation which the practice of pathology bears to science. The chief application of plant pathology is to agriculture, and as so applied the main practical achievements may be summarized briefly as follows: (1) the control or partial control of various fungi, notably of orchard, vineyard, truck, and floral crops by sprays of copper compounds; (2) the substitution in many instances, notably on drupaceous hosts, of lime-sulphur compounds; (3) treatment by excision and the introduction of so-called tree-surgery; (4) the avoidance of susceptible varieties, for example, carnations, pears, strawberries, chrysanthemums, cowpeas, asparagus, and cantaloupes; (5) the development or utilization of disease-resistant or partially resistant strains, for example, asparagus, pears, watermelons, cowpeas, oats, wheat, flax, and cabbage; (6) the prevention of disease through knowledge of necessary alternate hosts, for example, pomaceous rusts; (7) the prevention of disease introduction by quarantine and inspection; (8) prevention through knowledge of mode or time of infection, or mode of transference,

for example, certain cereal smuts, bean and cotton anthracnose, cabbage blackrot, and potato scab.

"In this enumeration, the first 5 captions cover the major part of the early fruits of pathology, the easily gathered fruits, first ripe, and which could be harvested without deep, scientific knowledge. Such practices do not necessarily rest upon subtle principles, but are rather the outcome of cut-and-try methods of experience.

"The accident which led to the experiments which in turn brought into prominence the use of copper sprays and thence led to much that has been done to perfect sprays and dust applications is well known; also the taking over of the lime-sulphur mixture from the entomologist. The susceptibility of certain varieties of crop plants has led the farmer in the south to reject special types; for example, the Bartlett and Seckel pears, and some of the strawberries. The florist, likewise, has been obligedd to eliminate certain varieties of carnation. They would have done so had no science of pathology existed. Similarly, many of our so-called disease-resistant varieties were discovered by the farmer or are either not highly resistant or are of such poor quality that they are not used extensively.

"Lest I may be regarded as pessimistic concerning the relation of science to plant pathology, I shall say at once that though these large advances were made in the main empirically, their progress was in reality hastened and made easier by the faith and confidence fostered by basic knowledge in mycology, bactericlogy, and physiology; and definitely aided by advances in chemistry and special technique. With the remaining categories the dependence upon science is direct and evident. For example, knowledge of the alternate host relation in pomaceous rust and currant rust could not have been attained without the upbuilding of a broad knowledge of the rusts in general, indeed of the fungi as a whole; nor could the canker relation in apples (Glomerella, Sphaeropsis, Bacillus) have been found without knowledge of the nature and morphology of the causal fungi; and the same is true of the present troublesome citrus canker. Adequate quarantine inspection measures cannot be taken without definite knowledge of the identity, nature, and causes of disease. The quarantine question looms into particular prominence when we regard the subject of disease migration both interstate and international. The following are examples of diseases, the migration of which is more or less definitely known: pear blight, asparagus rust, grape anthracnose, cabbage club root, potato wart, potato blight, grape blackrot, and downy mildew, chestnut bark disease.

"Seed transference of disease is exemplified in the cabbage blackrot, celery leaf spot, and bean and cotton anthracnose. It is barely possible, but not at all probable, that this relation could have been discovered without intimate knowledge of the causal agents, but it really was a rigid, scientific method which gave us our present knowledge of these diseases. The valuable results of the work on cereal smut infection furnish a fine example of achievement in disease-prevention that could not have been attained without both basic knowledge in mycology and a technique enabling trustworthy experimentation.

"Upon entering a new biological territory, the first work is to collect and to classify, to know the material. So in the new field of plant pathology much

of the early work was descriptive. The number of important plant diseases that are reasonably well described in two volumes of the Report of the United States Department of Agriculture for the years 1887 and 1888 is remarkable.....

"With the general principles of treatment established and the field for discovery of new diseases dwindling in importance, the time has now come when further progress, with rare exception, must be the outcome of fundamental, special knowledge and crucial experiments.....

"Parasitic diseases present two chief elements, the host plant and the parasite. There is also, what is perhaps more important, the interrelation between these two and the factors of environment. It is with the study of these 5 elementary factors that pathology has to do. Large attention in the past has been given to the parasite, and in many cases it is the parasite alone which has been studied. Proportionately little study has been given to the relations existing between the host and the parasite, while the relations existing between environment and host, and environment and parasite, unquestionably of great significance, present a comparatively unworked field.

"I wish to call attention briefly to the types of problems that exist under the above analysis. Perfecting and stabilizing of the taxonomy and nomenclature of the parasites are of course of fundamental value to pathology.....

"In connection with these problems arises the question of host relation and of biological specialization, as best exemplified, perhaps, in the rusts and the powdery mildews..... This forms a large and enticing field, in which much good work has been done, but a vast amount remains still to be done.

"Coupled with these problems, come of necessity physiological, morphological, and cytological studies.....

"Morbid histology of the various diseases presents a large field for activity. Concerning many diseases our knowledge in this regard is as yet really nil. It may be in many cases that such knowledge will not affect practice, but in many cases it surely has done so. Its utility appears clearly in relation to cereal smuts, tree surgery, etc.

"The whole question of disease-resistance and susceptibility is fundamental and practical, as the age incidence of disease; the causes of resistance, whether mechanical, chemical, or physiological; the factors of air, soil, or heredity causing variation in resistance, and the possibility of artificially changing these factors. Breeding for disease-resistance is a special problem of extreme importance, involving knowledge of the factors of resistance and susceptibility, the needs of cultural conditions, and laws of breeding. Notable progress has been made with many crop plants, as oats, cabbage, asparagus, cantaloupes, carnations, flax, melons, and cowpeas.

"Hibernation of the parasite has been the subject of much study. In some cases it offers the key to prophylaxis. It is, of course, inseparably linked in many cases with life history studies, and seems also sadly in need of study by those with sound ecological training. Indeed, an ecological study of certain plant parasites, with analysis of the environmental factors and with environments

under experimental control, touching also upon seasonal relations, should be very productive. Problems abound on the border fields between mycology, physiology, ecology, and pathology relating to the age relation to disease, to mode of infection, to the climatic and seasonal relations of the parasite, to increase and decrease of susceptibility with changes of environment, to the results of varying the mass of the inoculum, and to change of the virulence of the pathogen with environment.

"Epidemiology (to borrow the term from medical usage) is clearly linked with these topics. There is a vast amount of uncorrelated information in the literature concerning the relation between temperature, rainfall, etc., and various diseases, but there is ample room for a complete "epidemiological" study of any one of many really serious diseases.

"A large field involving knowledge of extreme value and demanding ingenuity of experiment is that of pathogen transference. We know a little about transference by insects, but very little about wind and other agents.

"Fungicides and their action are in need of more study. It is remarkable if accident has really given us the best fungicides in copper sulphate and lime sulphur. Our knowledge of their action and of their composition can be increased; so, too, the time to apply them and the strength to use. The exact time of application is undoubtedly of much importance, in some diseases, notably apple rust, the variable results are presumably linked with the time relation. Exact knowledge of such relation is needed in many cases. The subject of fungicide injury to fruits or foliage also arises here.

"There are many diseases which have been described in a preliminary way, the causes of which are not yet known. Some of these are of great injury, notably the various so-called "mosaics", peach yellows and rosette. .....It is not too much to hope that some of these will give up their secret under proper attack; some seem to have done so recently; for example, beet curly-top and the crown-gall. The status of others, such as Jonathan spot, tomato blossom-end-rot, tobacco mosaic, and numerous other mosaics, is not so clear. There is here opportunity for good descriptive work that we may know definitely with what conditions we have to deal. When the anatomical, histological relations are definitely recorded, we shall at least be able to classify these various types, and to know, for example, whether in reality the various things that we now call mosaic are of similar or different nature. Abnormal enzyme relations have been invoked to explain some disease conditions, but in general such explanations lack conclusiveness, and certainly lack practical application." - Stevens, F. L. Problems of Plant Pathology. Botanical Gazette 63: 297. April, 1917.

The mosaic problem.

In discussing problems connected with the insect transmission of plant diseases, Gardner (2) dwells at length upon the mosaic type of diseases, not only with reference to dissemination but also upon the problems of cause and control. He suggests the following five phases of the problem which devolve upon the plant pathologists: "1. The nature of the mosaic contagium, infective principle or

virus. 2. The physiology of infection. 3. Transmission by other means than insects. 4. Host range of each virus, with especial reference to wild carriers of infection. 5. Development of disease-resistant varieties." He invokes the aid of the entomologists in solving the insect transmission phase of the problem. (For a further discussion of this problem as related to insects see Chapter XII).

Non-parasitic diseases.

The group of so-called "physiological" diseases of plants still affords some of the most perplexing problems with which the plant pathologist has to deal. While in a general way it is conceded that such diseases as bitter-pit and cork in apples, internal brown spot in potatoes, and blossom-end rot in tomatoes are related in some way to the water balance in the plants, yet there is diversity of opinion as to just exactly how this lack of balance brings about the injury as witness the many different theories which have been advanced to explain the injury to cells observed in bitter-pit of apples. (See under bitter-pit in Part II of this manual).

In 1915 Lipman (4) suggested what he chose to call a new phase of the problem of "physiological" diseases. He proposed that the general idea of malnutrition with respect to nitrogen should be given consideration in connection with certain die-back and mottle-leaf troubles in California. This opens up the whole question of the relation of soils and soil constituents to certain unhealthy conditions in plants.

Fungicidal studies.

By no means all of the problems connected with fungicides have been solved. Some of the questions yet to be answered center around such items as the following: (a) The relative value of different chemicals as fungicides. (b) The best methods of making them up into sprays. (c) The relative merits of dusting versus spraying. (d) The use of spreaders and stickers. (e) The elimination of fungicidal injuries.

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(3) Grossenbacher, J. G. Some neglected phases of phytopathology. Phytopath. 5: 155. June, 1915.

(4) Lipman, Chas. B. A suggestion of a new phase of the problem of physiological diseases of plants. Phytopath 5: 111. April, 1915.